eRD14 PID consortium

Integrated particle identification for a future EIC – Progress Report

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Contacts: 1) TOF and LAPPD, 2) RICH, 3) high-B, 4) DIRC and eRD14, 5-6) LAPPD

Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, BNL, January 28-29, 2016

Participating institutions

- Abilene Christian University (ACU)
- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Catholic University of America (CUA)
- Duke University (Duke)
- Georgia State University (GSU)
- GSI Helmholtzzentrum für Schwerionenforschung, Germany (GSI)
- Howard University (HU)
- Istituto Nazionale di Fisica Nucleare, Italy (INFN)
- Jefferson Lab (JLab)
- Los Alamos National Lab (LANL)
- Old Dominion University (ODU)
- Universidad Técnica Federico Santa María, Chile (UTFSM)
- University of Illinois Urbana-Champaign (UIUC)
- University of New Mexico (UNM)
- University of South Carolina (USC)
- Yale University (Yale)

Jefferson Lab

EX UMBRA IN SOLEM

BROOKHAVEN NATIONAL LABORATORY

ILLINOIS
1867
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

OLD DOMINION UNIVERSITY

UNIVERSITY OF SOUTH CAROLINA
1801

THE UNIVERSITY of NEW MEXICO

CUA
DEUS LUX MEA EST

Argonne NATIONAL LABORATORY

GSI

GEORGIA STATE UNIVERSITY 1913

ACU

LUX ET VERITAS
YALE

1867
HOWARD UNIVERSITY

Duke UNIVERSITY

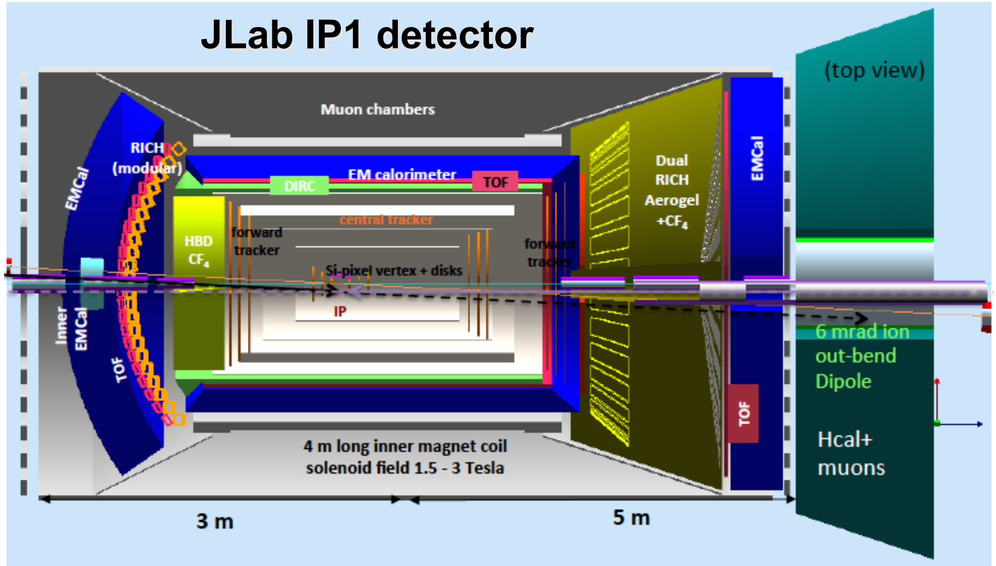
INFN

Los Alamos NATIONAL LABORATORY
EST. 1943

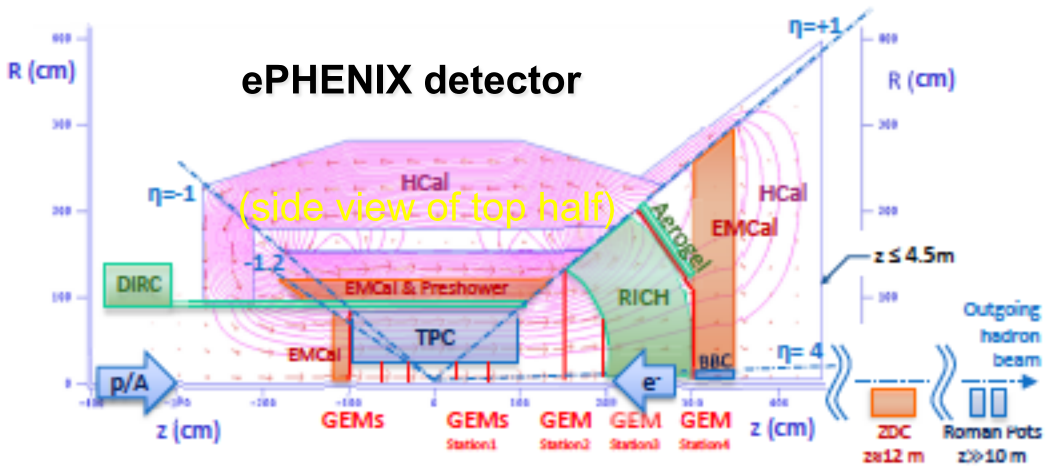
Outline

1. Introduction
2. Modular aerogel RICH
3. Dual-radiator RICH
4. DIRC
5. Sensors in high magnetic fields
6. LAPPDs
7. Time-of-Flight (TOF)
8. Inter-consortium PID: e/π
9. Summary and Outlook

eRD14 systems in some EIC central detector concepts



(approximately to scale)



JLab IP1

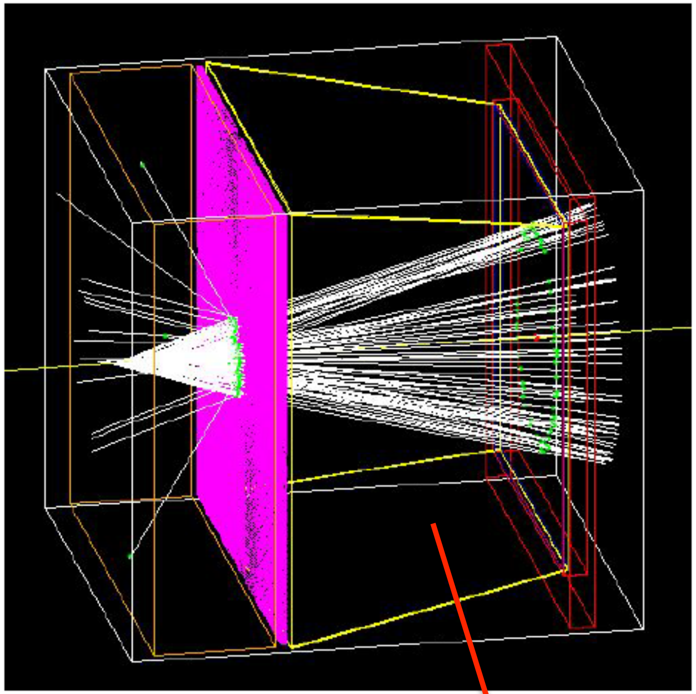
- 4π TOF (for bunch identification)
- DIRC in barrel (compact "camera")
- Dual-radiator RICH in hadron endcap
  - Outward-reflecting mirror
- Modular aerogel RICH in electron endcap
- HBD (with TPC?) in electron endcap
  - Threshold e/π Cherenkov also possible

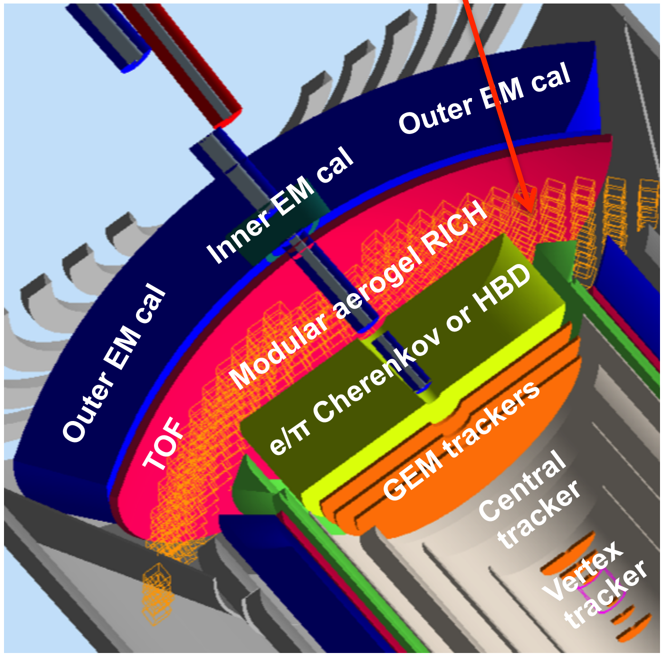
ePHENIX

- TOF (endcaps and/or barrel)
- DIRC in barrel (GlueX-like?)
- *Gas RICH in hadron endcap (eRD6)*
- Modular aerogel RICH in hadron endcap
  - Ring along outer part of the gas RICH
- *dE/dx in TPC (eRD6)*

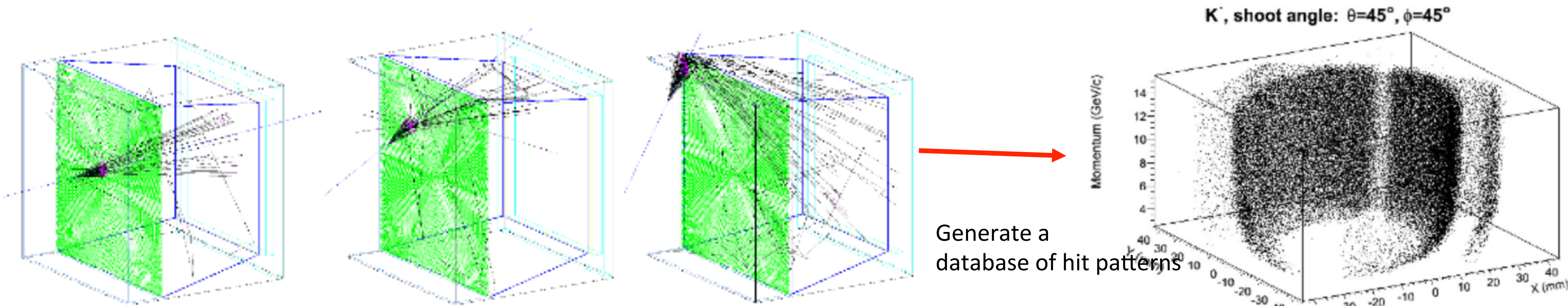
Modular RICH

- Ongoing MC studies
- Prototype test
- LANL LDRD proposal





Generic purpose analysis packages
- max-likelihood method

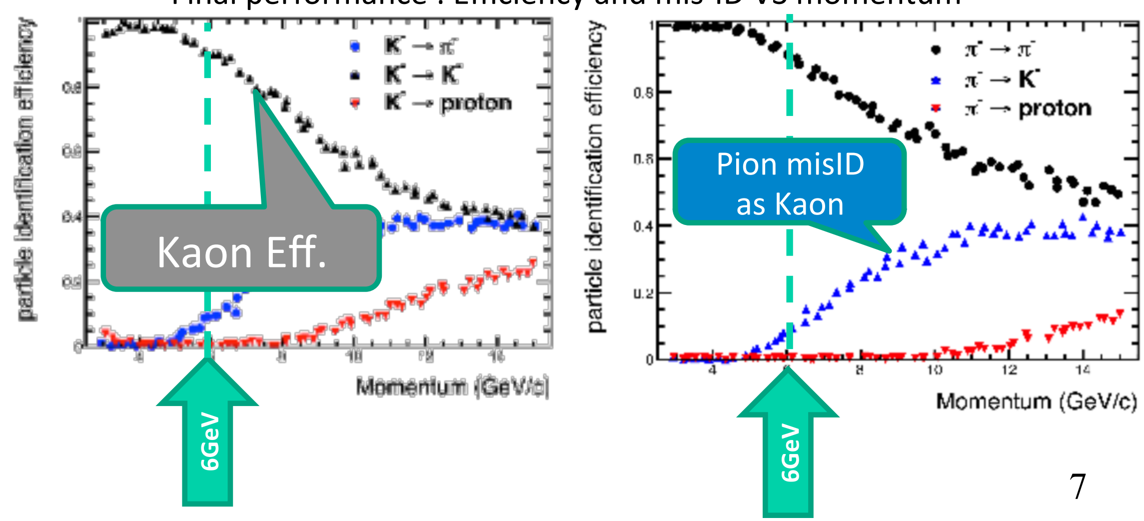


Kaon database illustration

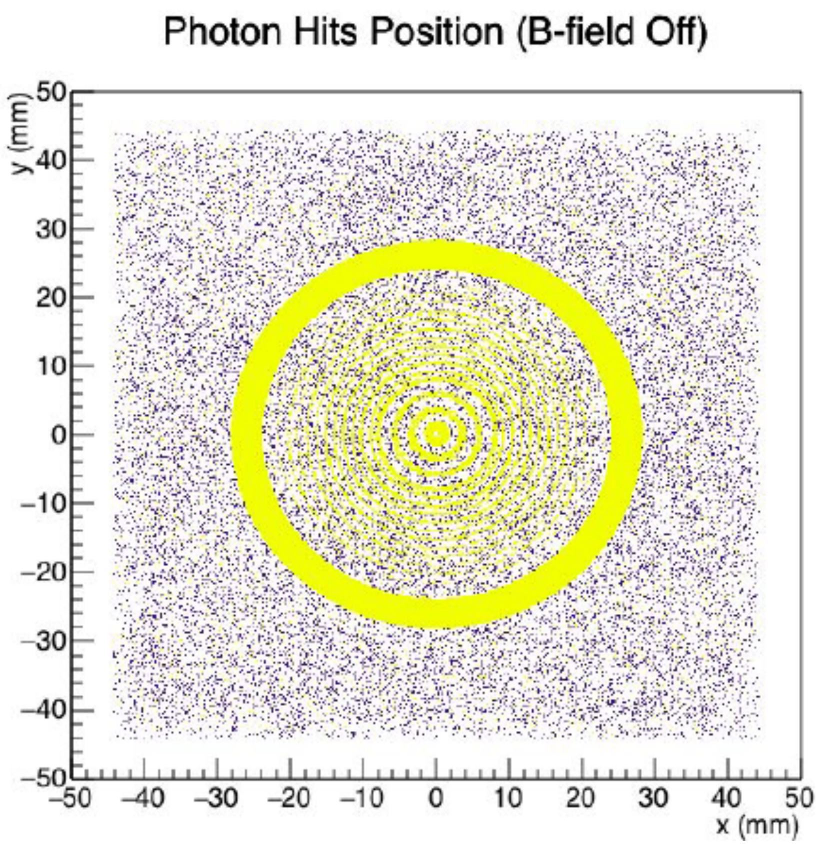
Next:
- Fold into larger environment
  - True momentum, angular distributions, particle ratios
- Optimize:
  - Refractive index
  - Thickness
  - Cutoff wavelength
- Determine:
  - Minimum aerogel quality
  - Maximum pixel size

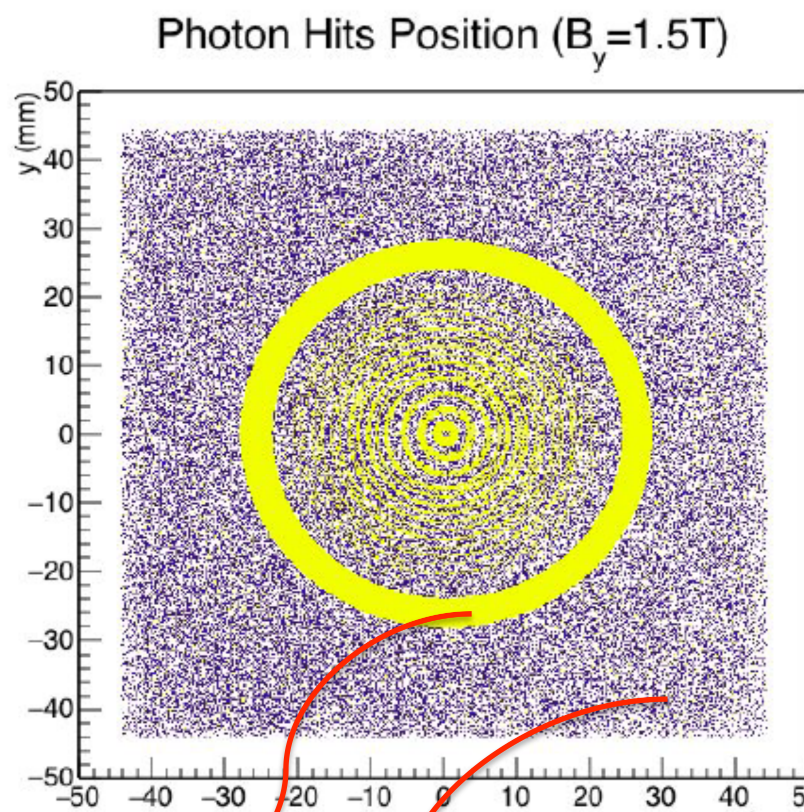
Likelihood matching by comparing an event vs. database

Final performance : Efficiency and mis-ID VS momentum

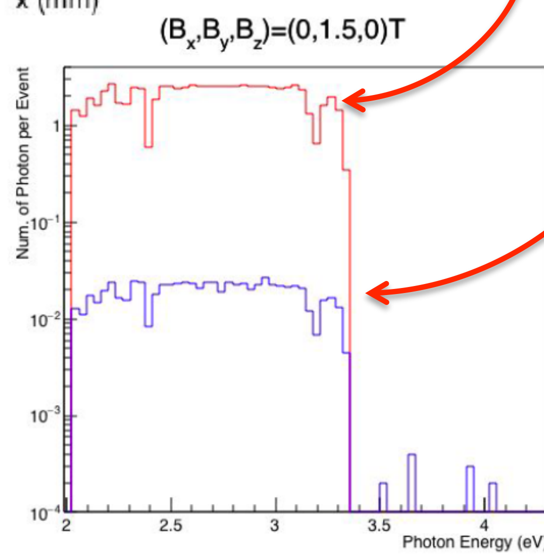


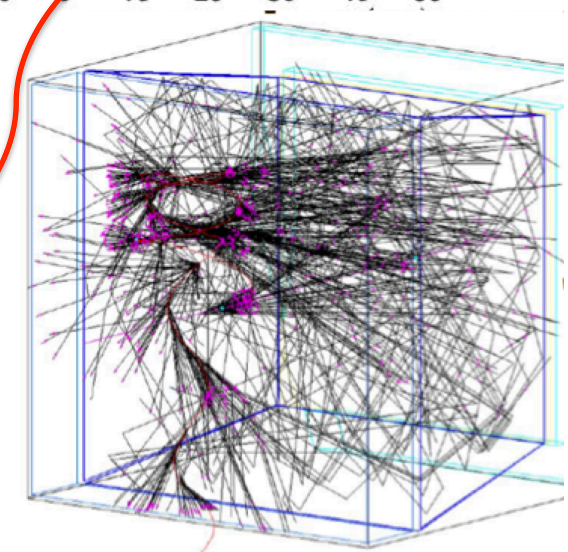
Background caused by B-field





Delta electrons cause background hits, and get worse in a B-field.
But still x100 fewer than 'signal' photons

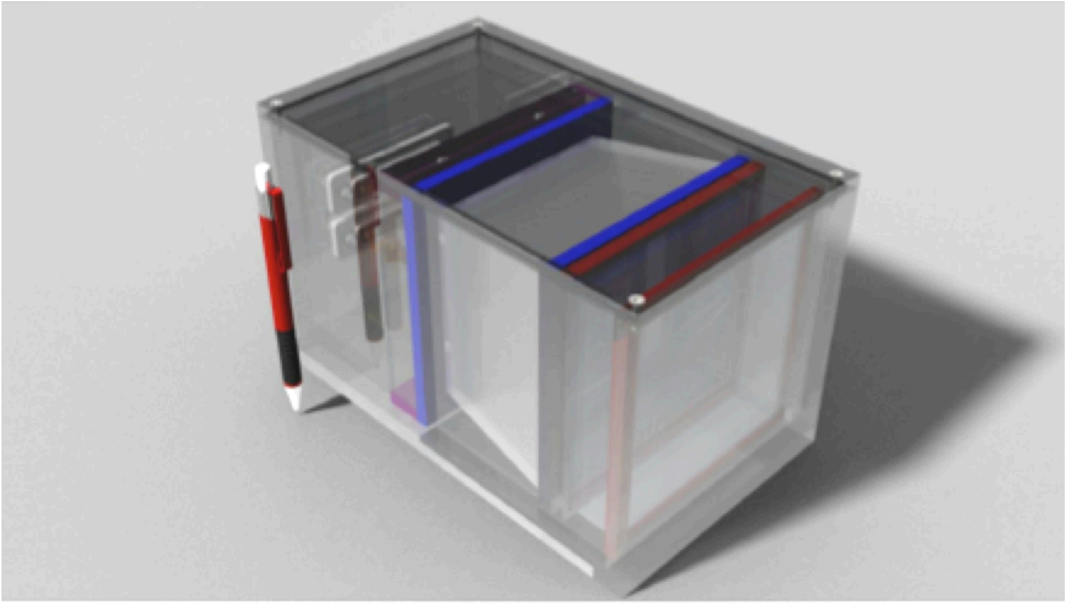


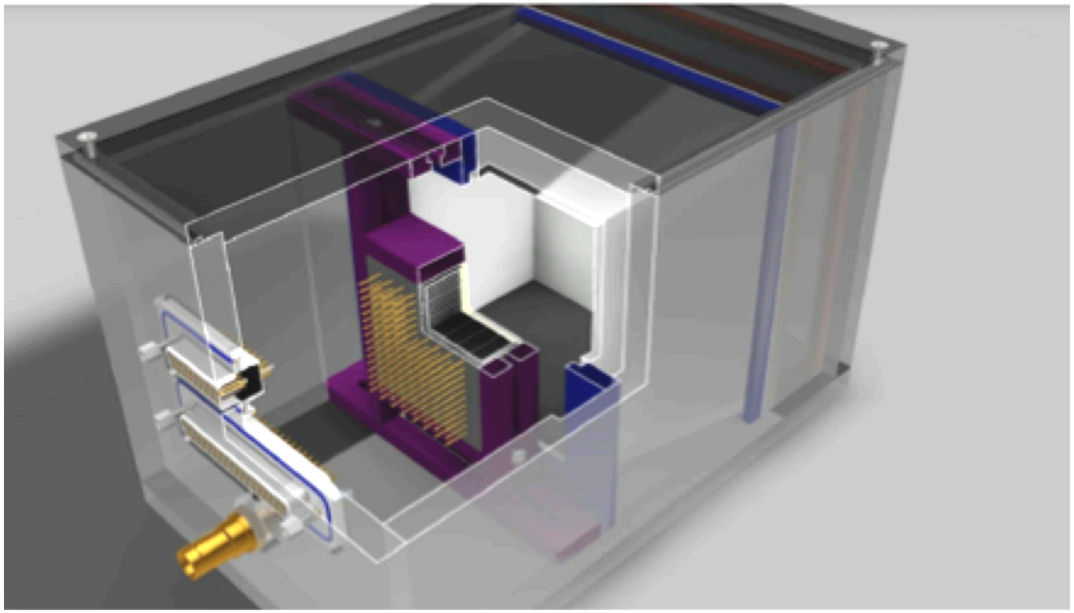


Prototype and beam test

A prototype of the modular aerogel RICH is under construction at Georgia State University

The plan is to have a beam test in April of 2016 at Fermilab



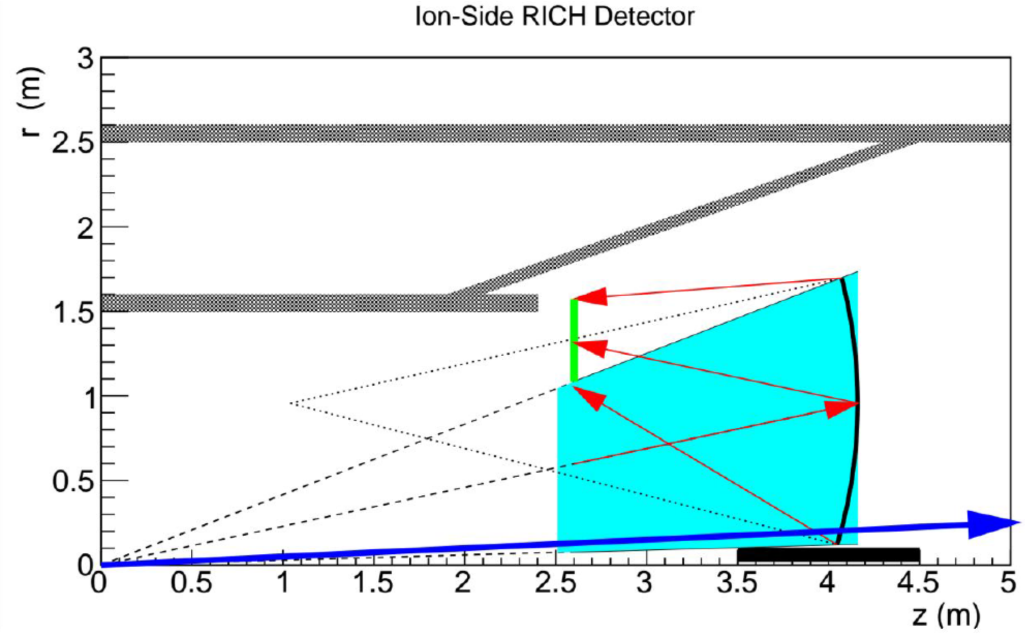


- Aerogel samples from Jlab and LANL
- Readout with a multi-anode PMT

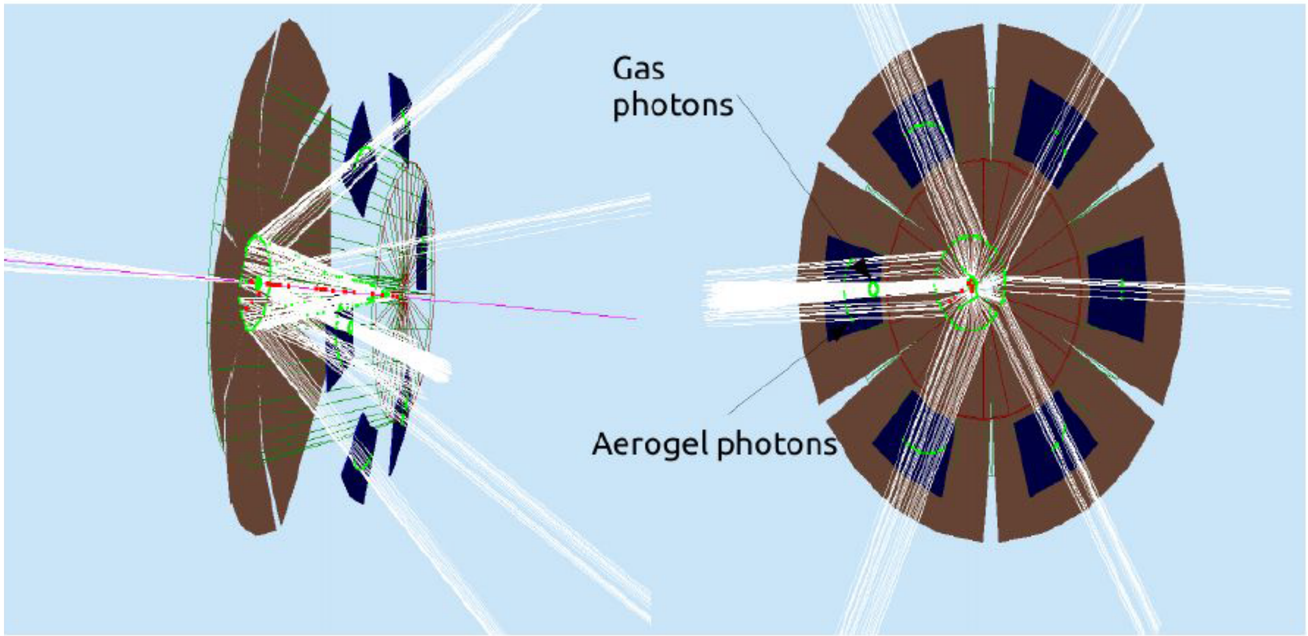
Dual-radiator Concepts

JLEIC design geometry constraint:
 ~160 cm length

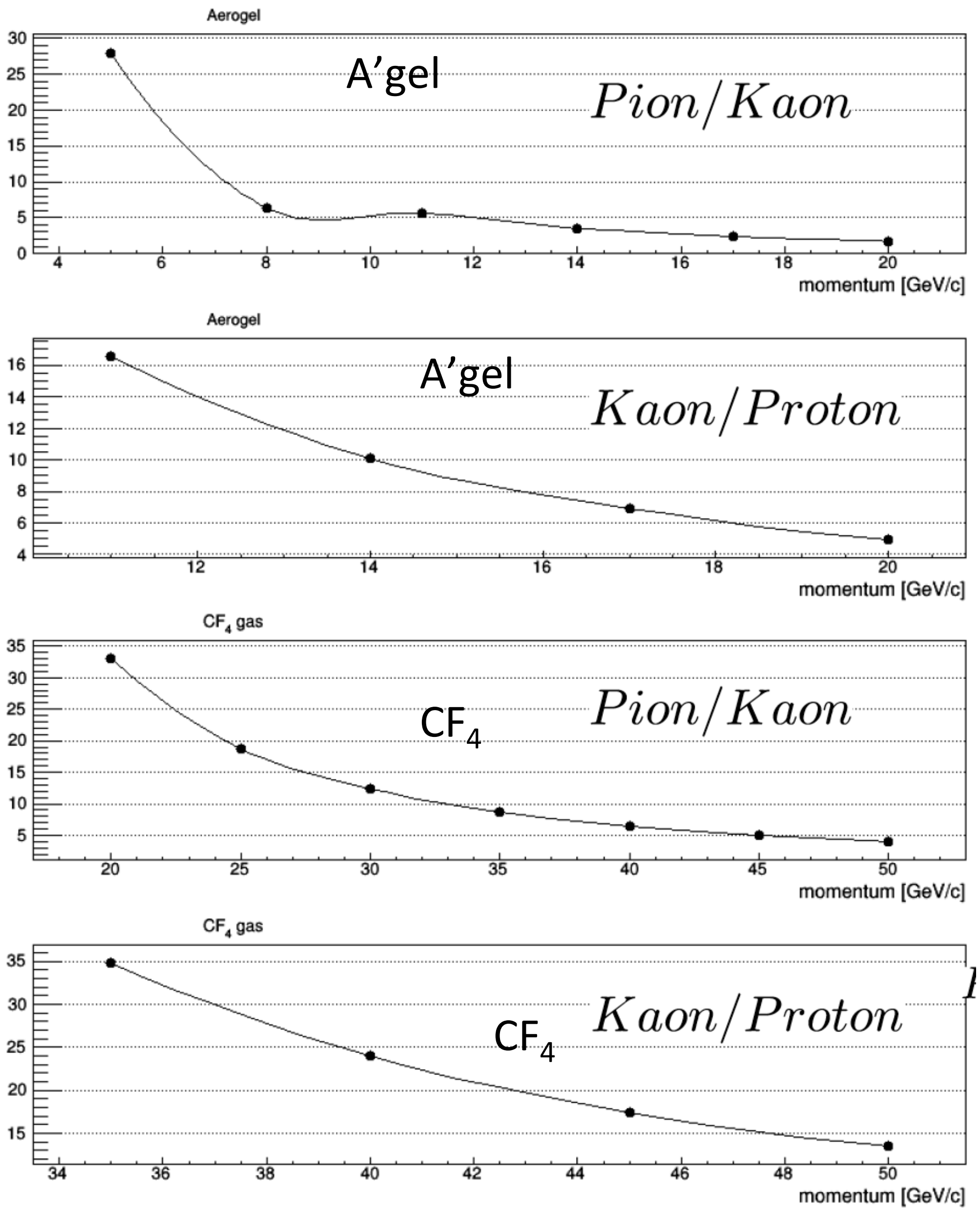
Aerogel in front, followed by CF_4



G4 implementation with 6 mirrors and 6 readout arrays

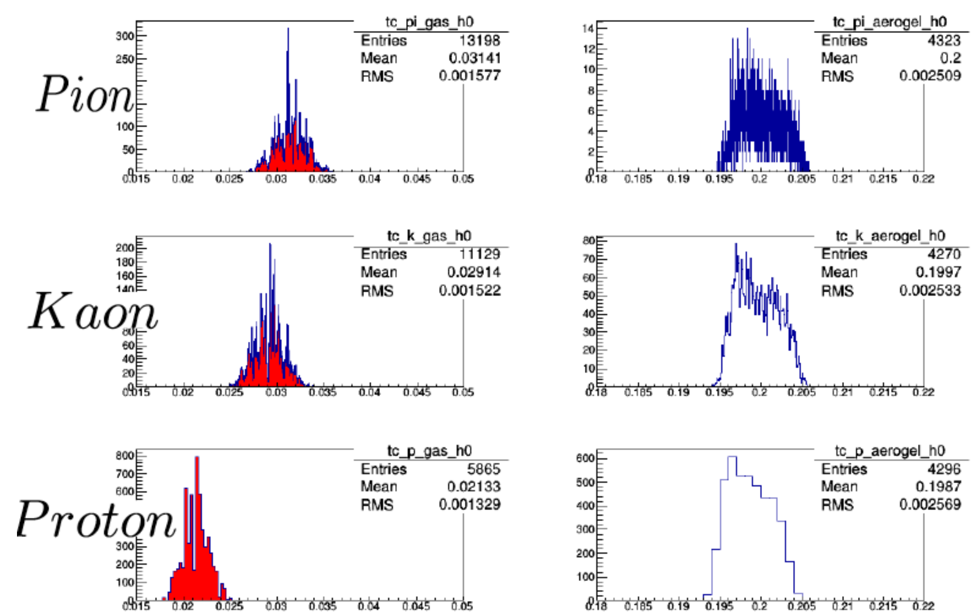


Particle separation - #sigmas



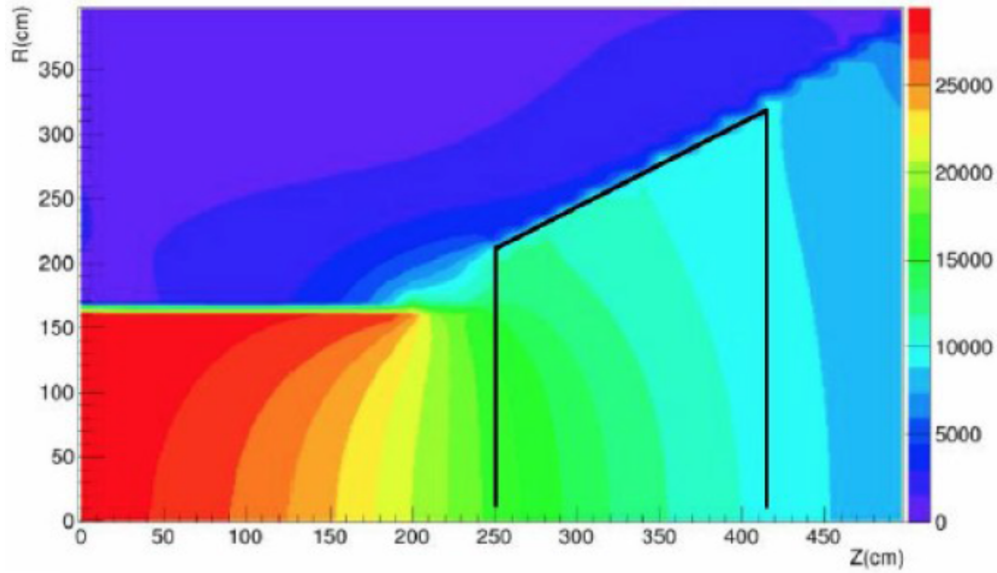
- G4 particle generation
- Indirect ray tracing algorithm
- No B field yet
- No track uncertainties yet
- 3mm pixel size

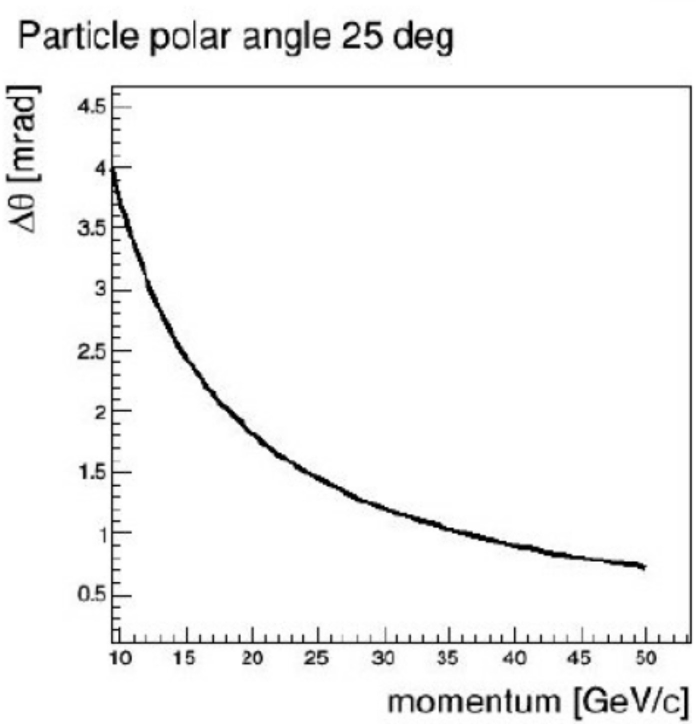
Example: 40 GeV tracks, at 3 degrees:



Effects of magnetic field

- Field components transverse to the track smear the ring resolution
- Can be minimized by shaping the field



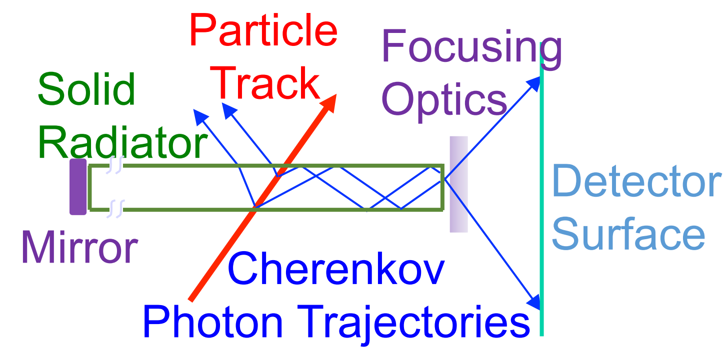


This error is of the same order as other errors (tracking, pixel size, chromatic)

Plans for the next 6 months

- Add B-field to full reconstruction
- Add tracking resolution
- Define required sensitivity for the readout (UV and visible)
- Evaluate other configurations

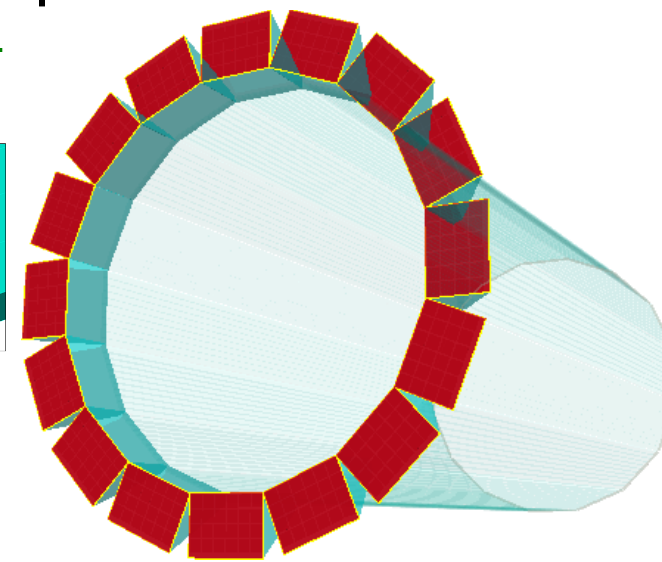
DIRC



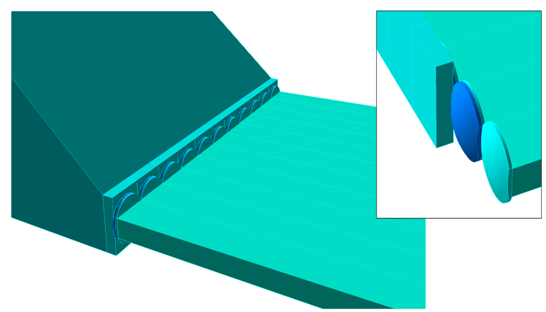
High Performance DIRC simulations

- DIRC@EIC with 3-layer lens is capable of 1 mrad Cherenkov angular resolution per track
- 3σ separation capability: p/K@10GeV/c, π/K@6GeV/c, and e/π@1.8GeV/c
- General paper on high resolution DIRC will be published in JINST

High performance DIRC in Geant 4

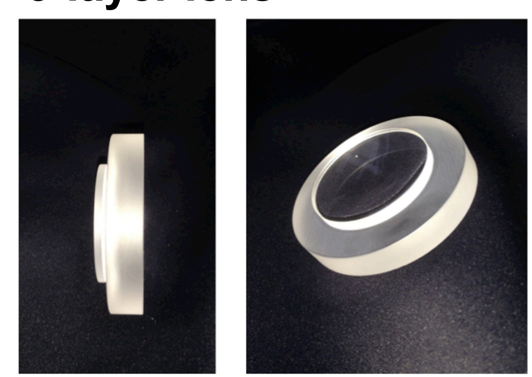


Experimental tests of 3-layer lens:



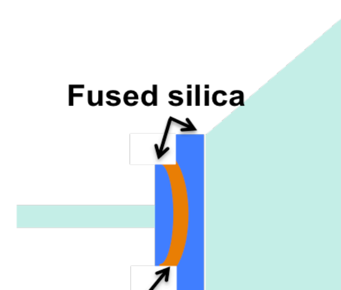
- Mapping focal plane
- Radiation hardness test
- Performance in prototype placed in particle beam (synergy with PANDA Barrel DIRC group)
- Separated paper on properties of 3-layer lens is planned

3-layer lens



Tilted Detector Plane

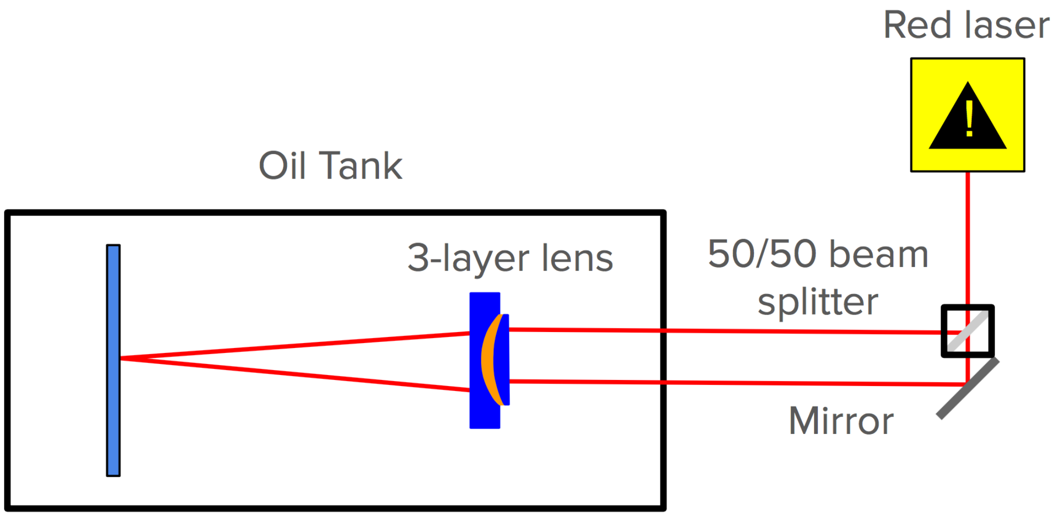
- Sensor tests at high B facility showed possibility of recovering part of the signal
- Optimized lens design allows to tilt the focal plane and place sensors perpendicular to the B field



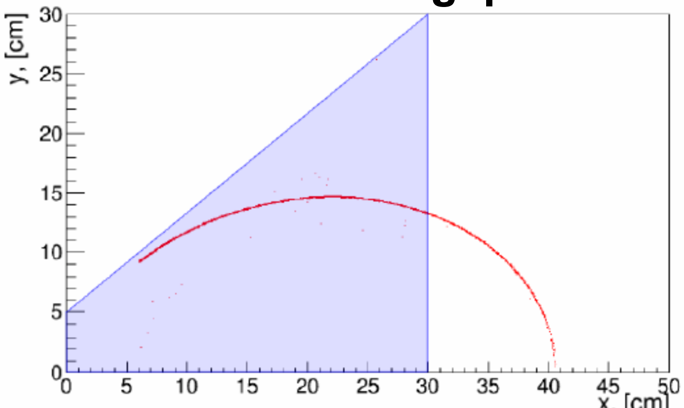
DIRC 3-layer lens – optics

Mapping focal plane of 3-layer lens:

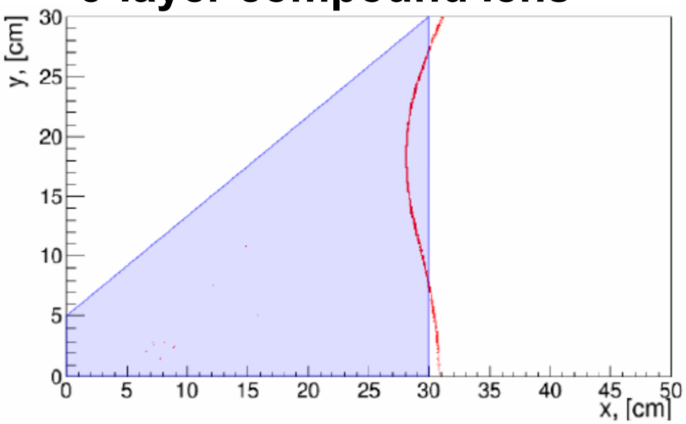
- Lens holder designed to rotate in two planes
- Setup ready to measure and already commissioned with standard lens



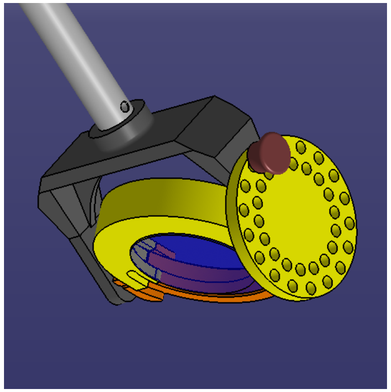
Geant4 simulation of focal plane: Standard air gap lens



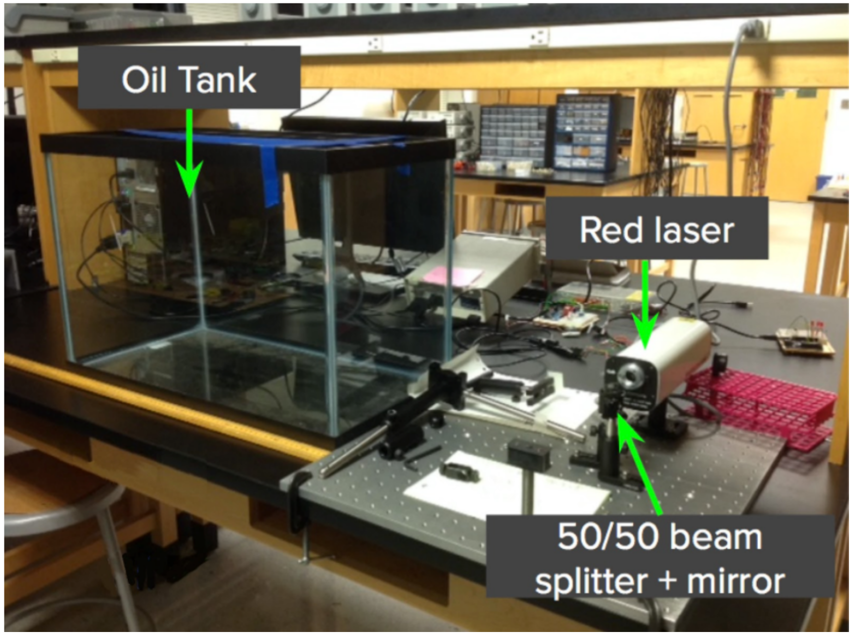
3-layer compound lens



Lens holder



Laser setup at ODU to map the focal plane

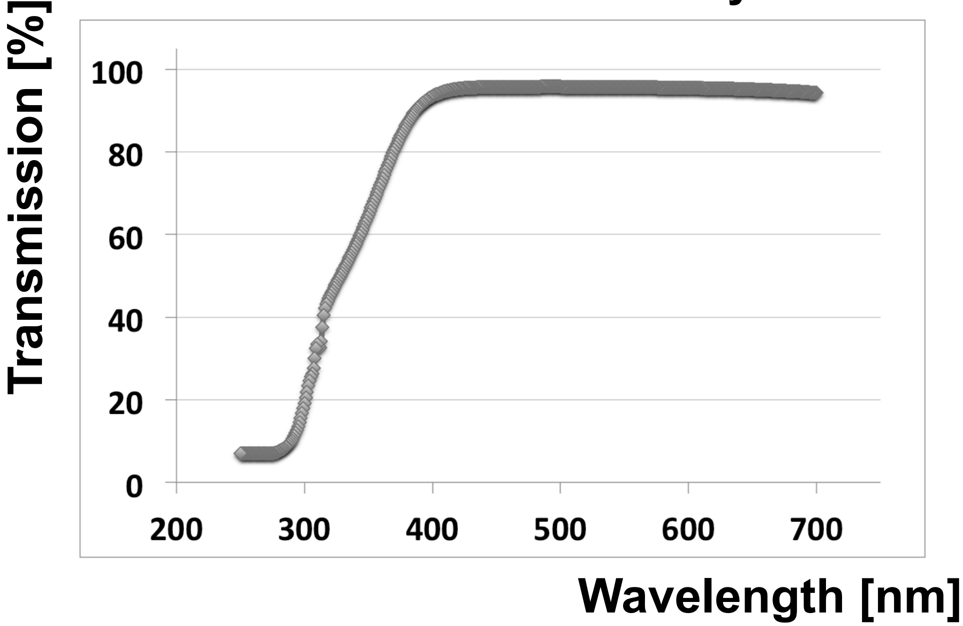


DIRC 3-layer lens – radiation hardness

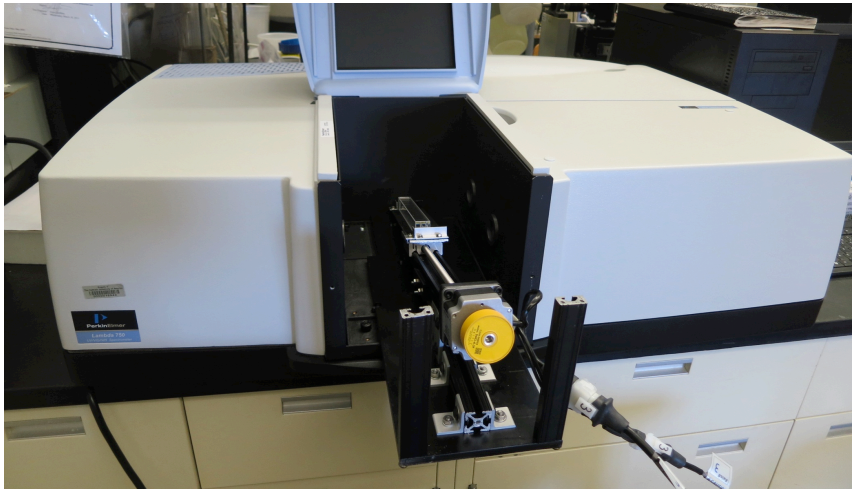
Radiation hardness tests at CUA

- Irradiating coated 3-layer lens and pure N-Lak33 sample
- Transmission measurements using monochromator with 0.2% reproducibility
- Irradiation using 160kV X-ray source
- In parallel to measurements we are in process of preparing for ordering next prototype of 3-layer lens

Measured transmission of 3-layer lens



Monochromator



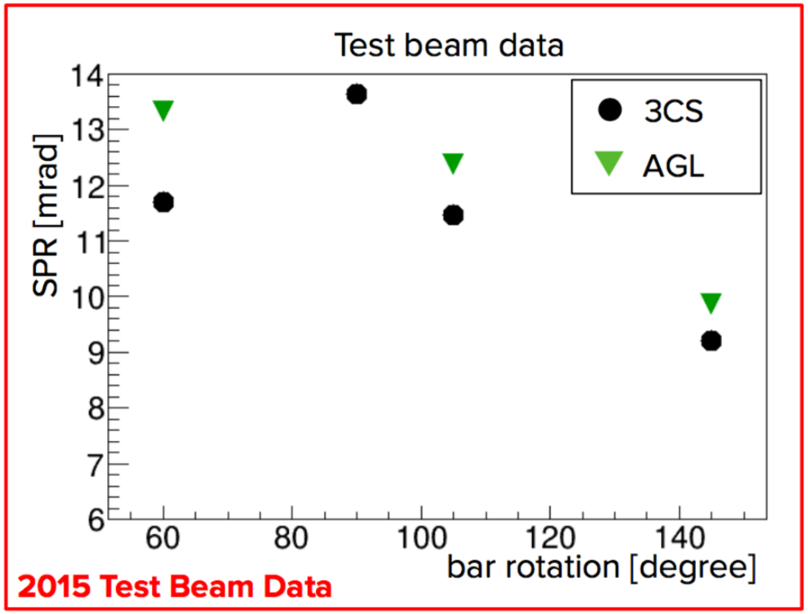
X-ray source

DIRC 3-layer lens – analysis of test beam data

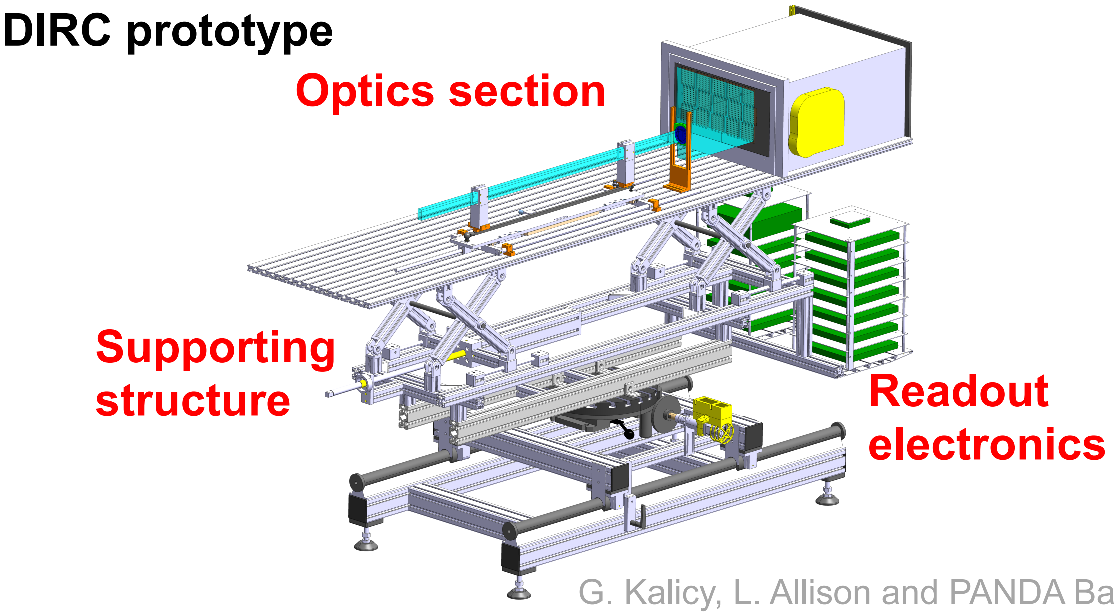
Performance of 3-layer lens in particle beam

- 3-layer lens (3CL) improves both photon yield and single photon resolution (SPR) in comparison to standard lens
- Resolution can be still improved with better event and hit selection
- Work on data analysis G. Kalicy, L. Allison (ODU), and R. Dzhygadlo (GSI)
- Including charge sharing in simulation will allow final validation of simulations with the test beam data

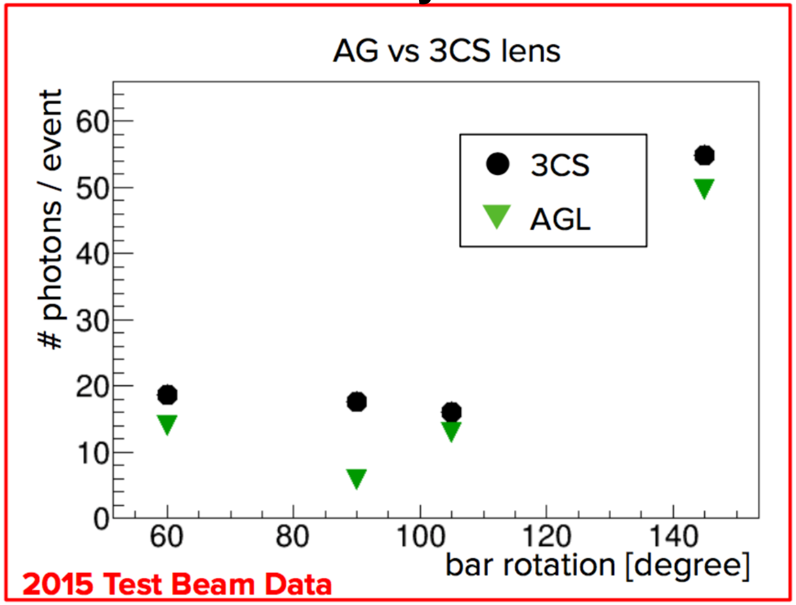
Single photon resolution



PANDA Barrel DIRC prototype



Photon yield

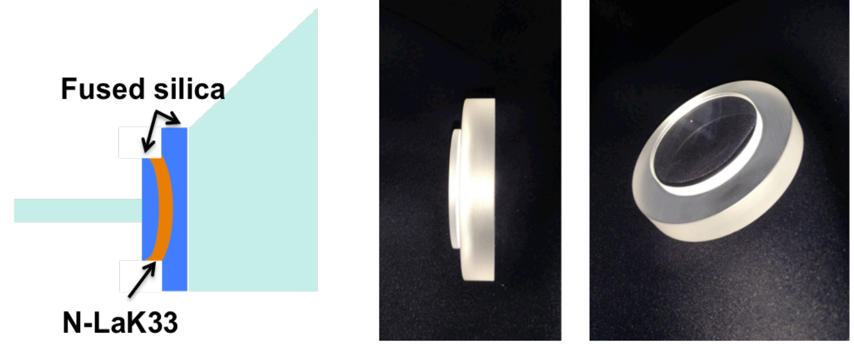


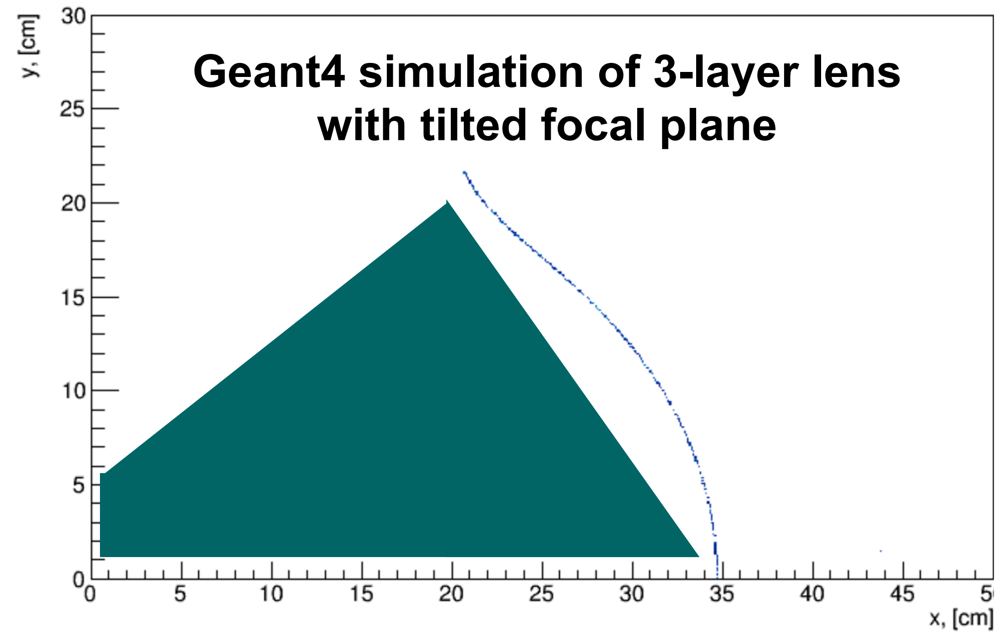
G. Kalicy, L. Allison and PANDA Barrel DIRC group

DIRC– tilted sensor plane

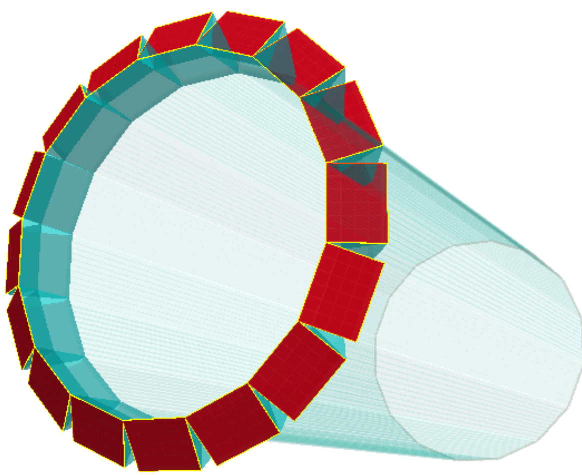
- High-B sensor tests show that optimization of voltages across MCPs allows to recover gain for perpendicular fields (θ = 0°), but performance deteriorates rapidly at larger angles
- Selecting different (larger) radii for the different lens layers allows to tilt the focal plane, allowing to align the sensors with the field lines
- Larger radii means that lens will be thinner which will improve photon yield
- Tilt angle be optimized for field and performance

3-layer lens





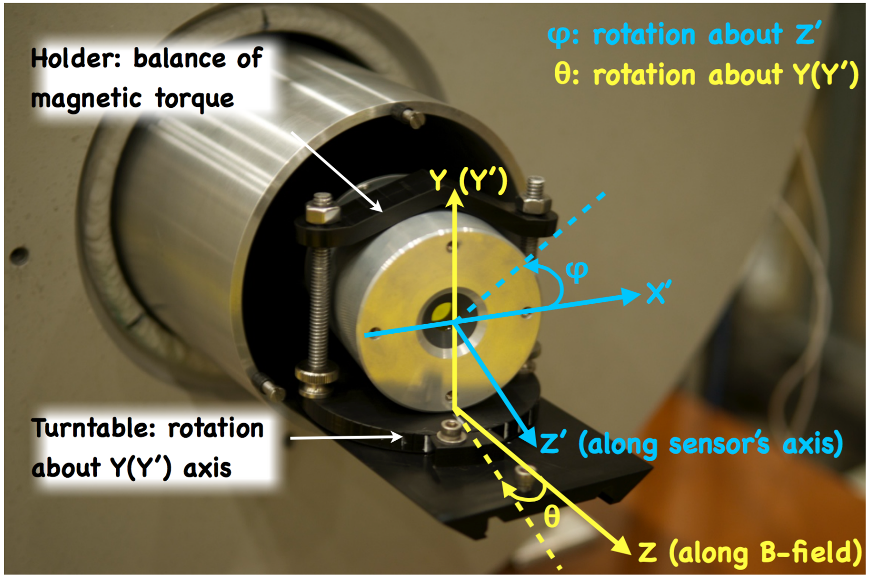
High Performance DIRC with tilted detector plane in Geant4



G. Kalicy, R. Dzhygadlo, L. Allison

Sensors in high B-fields

5T Magnet bore with opened Dark box holding one of the tested sensors



Funded Activities

- Requisition of parts and manufacturing of custom components for sensor measurements, such as custom holders, light box end caps, HV divider, etc.
- MCP-PMT gain measurements up to 5 T.

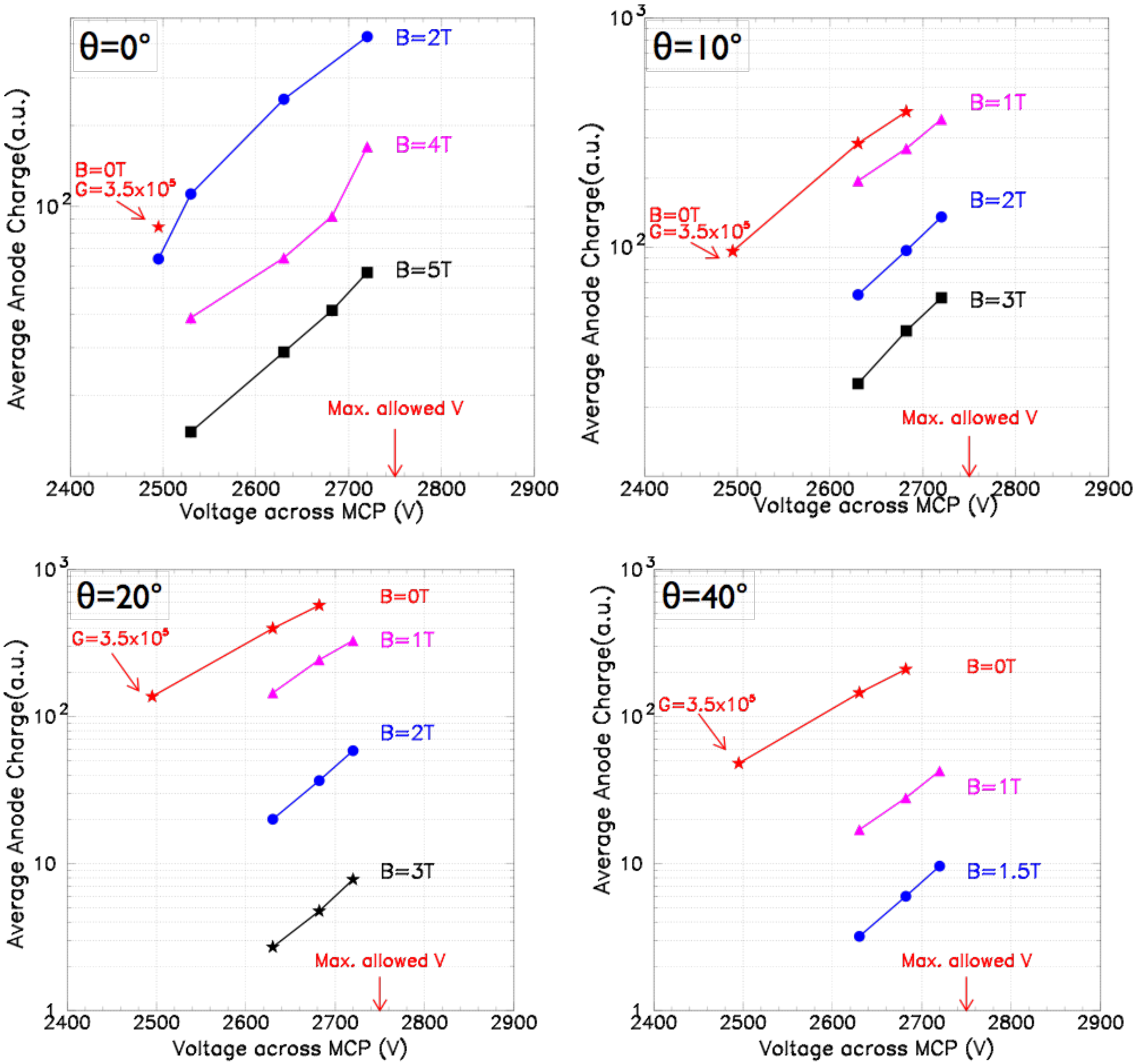
Progress

- Improvements to the setup and measuring procedure.
- Measurement of gain performance of Photek single-anode 3-μm PMT as a function of field, orientation, and independently varied high voltages across the MCP-PMT three stages: photocathode MCP, MCP–MCP, and MCP–Anode.
- Design of a universal HV divider, in collaboration with manufacturers, allowing to control the voltages across the three MCP-PMT– stages independently.

Future

- MCP-PMT gain and timing measurements of single- and multi-anode MCP-PMTs from different manufacturers for various operational parameters in B-fields up to 5 T.
- Development of GEANT simulation of MCP-PMT for studies of MCP-PMT performance in high B-fields for various design parameters.

High-B – gain as a function of MCP-MCP voltage



- Increasing the potential difference across the channel plates can help to recover the loss in gain due to the magnetic field.

- Gain recovery is strongly correlated with the angle between the MCP and field axes: the larger the angle, the more limited is the range of fields where the sensor can be operated at the same gain.

- At 0 deg, increasing $V_{cathode\text{-}MCP}$ and $V_{MCP\text{-}anode}$ above their nominal values does not seem to affect the gain performance.

- Additional optimizations for gain recovery need to be implemented if the orientation of the sensor relative to the field varies significantly.

- Data were obtained with a Photek PMT210 using a 3-μm MCP

Sensors in high B-fields

Future Work funded through EIC R&D

- **Main Goal**: to achieve an MCP–PMT design and operational parameters that are optimized for successful application in DIRC in the high magnetic field of the central detector at EIC

- **Effort**:

  - Continuation of our close collaborations with all main photo-sensor suppliers.

  - Construction of a universal HV divider that will allow to study gain recovery for different sensors.

  - Further MCP–PMT gain measurements of a variety of commercially available single- and multi-anode MCP-PMTs as a function of various operational parameters.

  - Development and implementation of a GEANT4 simulation of an MCP–PMT for optimization of design parameters.

  - Timing studies in high magnetic fields of various commercially available single- and multi-anode MCP-PMTs.

LAPPDs

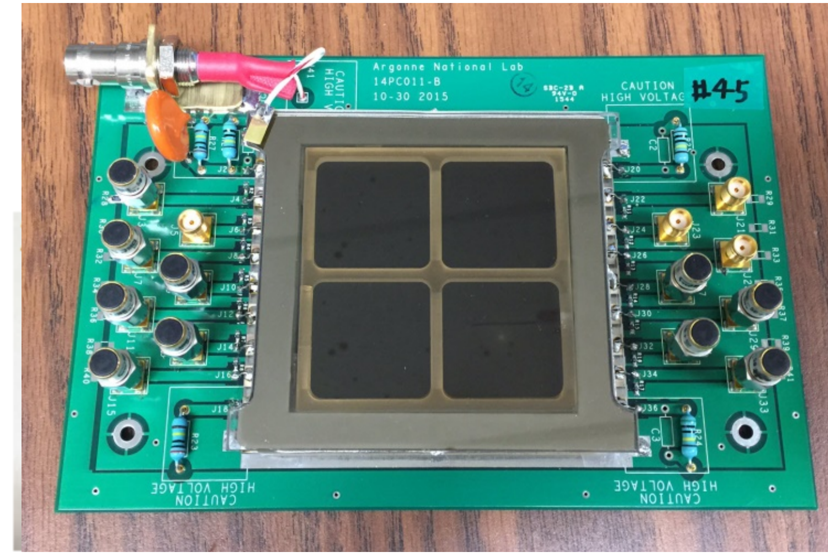
Funded work by EIC R&D funds
- Characterization studies at JLAB
- Magnetic field testing of JLAB sample

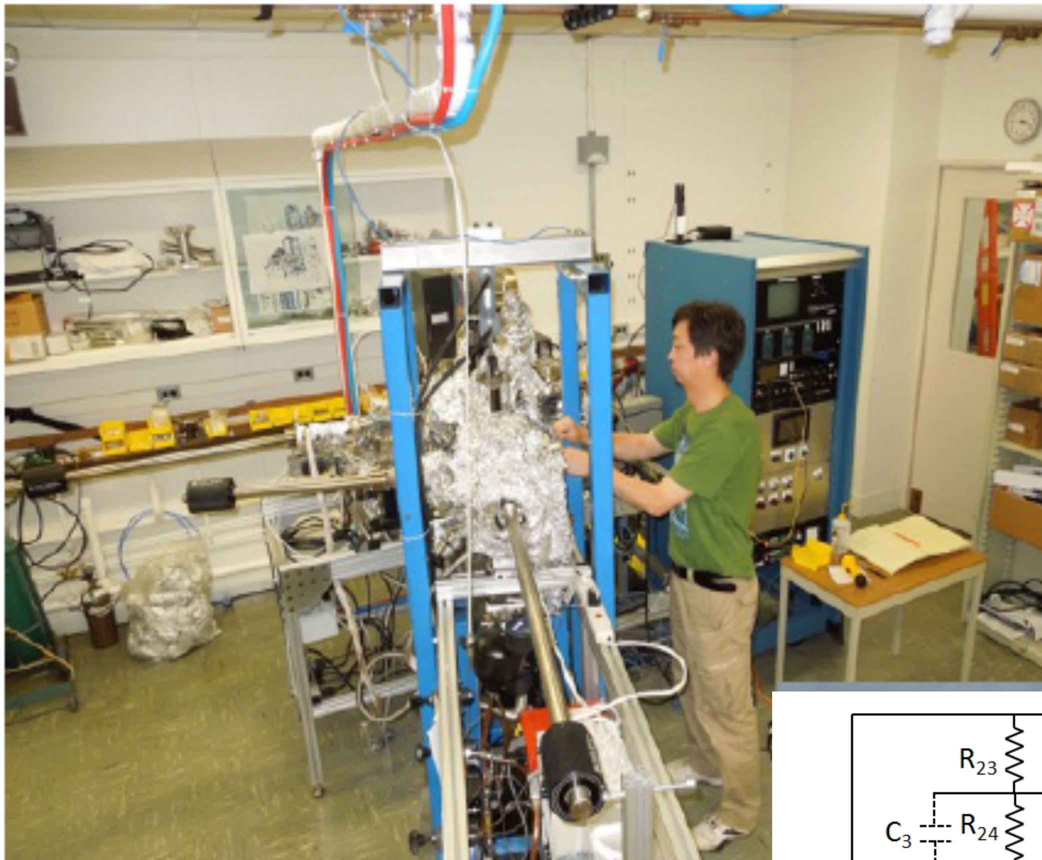
Future Work funded through EIC R&D
- Ready to fabricate UV range MCP-PMT
- Provide EIC-PID TOF, RICH devices for testing
- TOF testing at BNL
- Characterization of new JLAB sample

Current Progress
- Achieved 5 resistor chain design MCP-PMT
- Achieved 10 individual biased design MCP-PMT
- Detectors are ready to be sent out for testing and applications
- Magnetic field test of JLAB sample

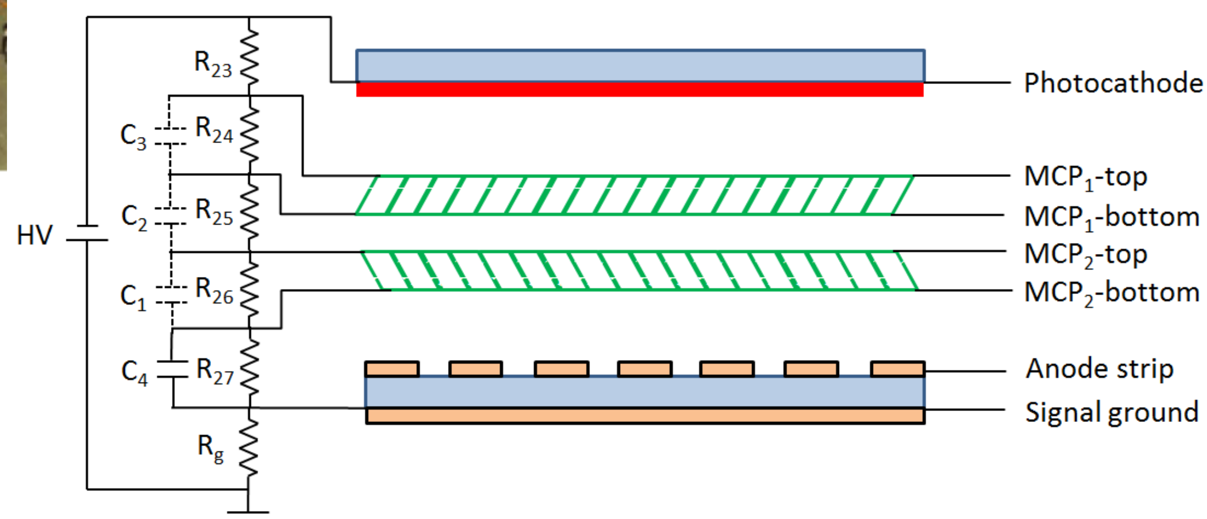
Future Progress
- Continue MCP photodetector fabrication as R&D platform
- Provide detectors for HEP application (ANNIE, LAr, Dual readout)
- Improvements in photocathode QE, wavelength reach (VUV)
- Optimize detectors parameters and readout for applications
- Cryogenic MCP detector
- Continue sample characterization

LAPPDs – MCP-PMT fabrication
New voltage divider design





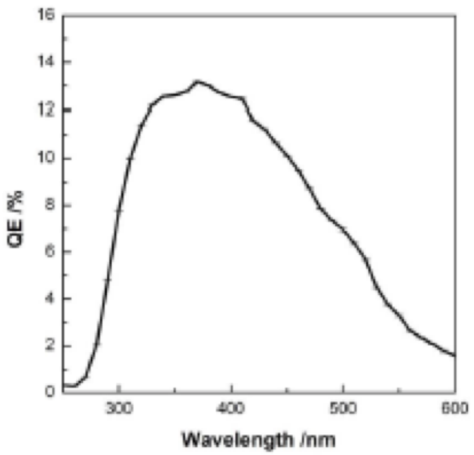
- A new readout board with a external resistor chain HV divider was designed for independently applying the voltages.
- The detector performance can be optimized by fine tuning the HV across each internal component

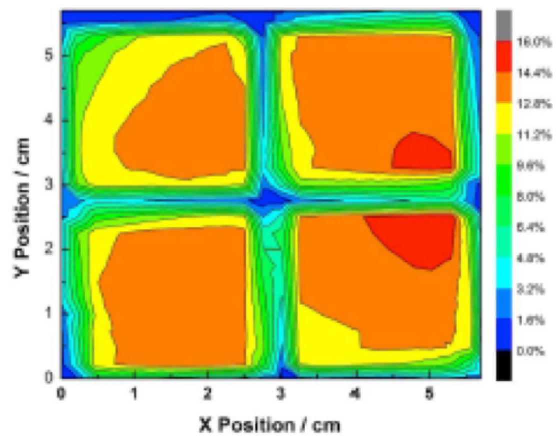


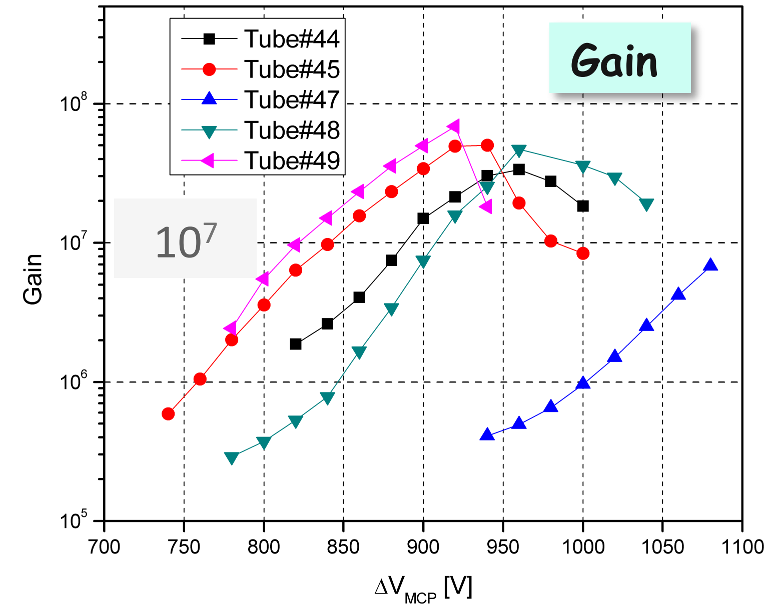
- Routine beginning-to-end fabrication with high yield
- Just met DOE milestone of 10 working detectors for CY2015
- Patent pending for biasing design

LAPPDs – IBD detector performance summary

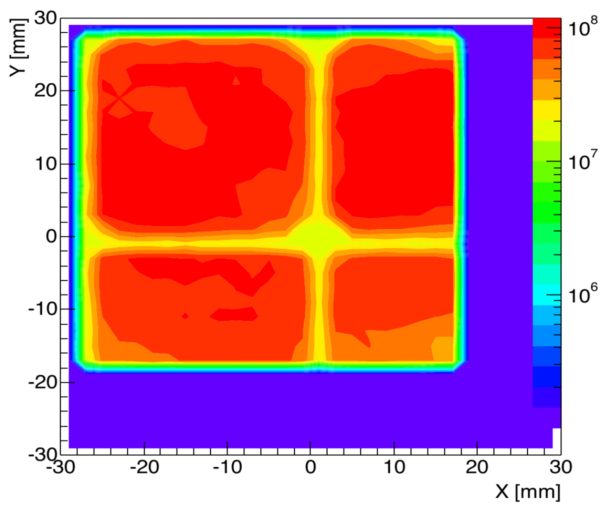
QE: 13.2% average
15.5% peak



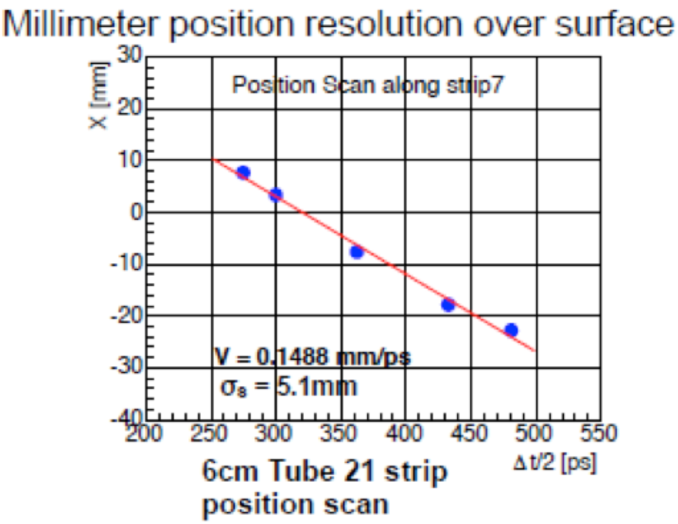




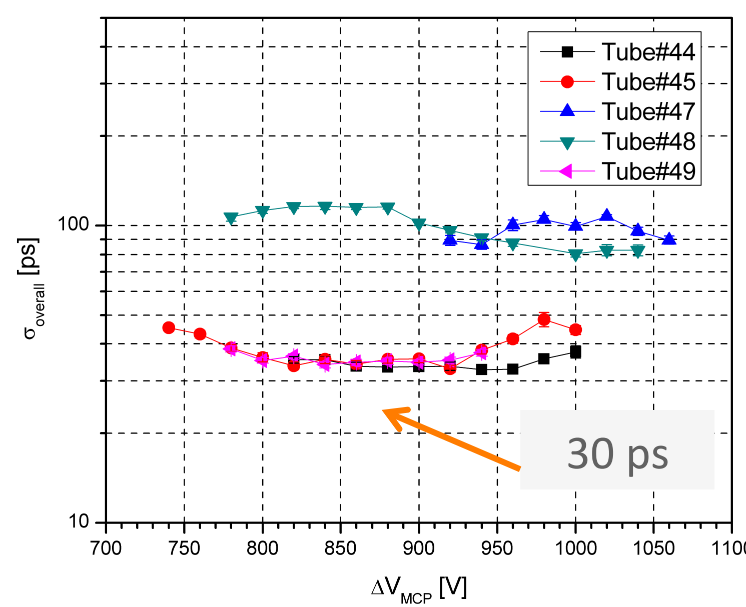
Uniformity scan
Npe~10



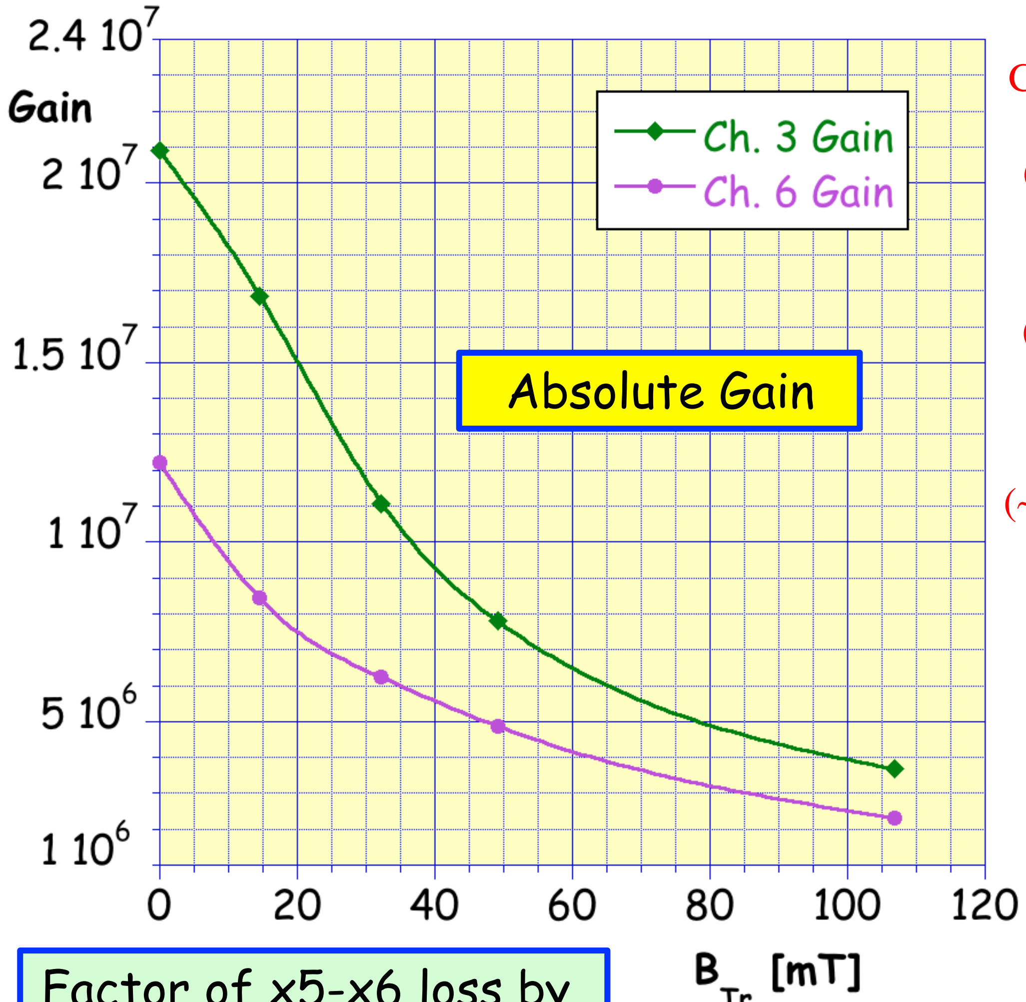
5 mm position
resolution



Overall time resolution (I.R.F.)



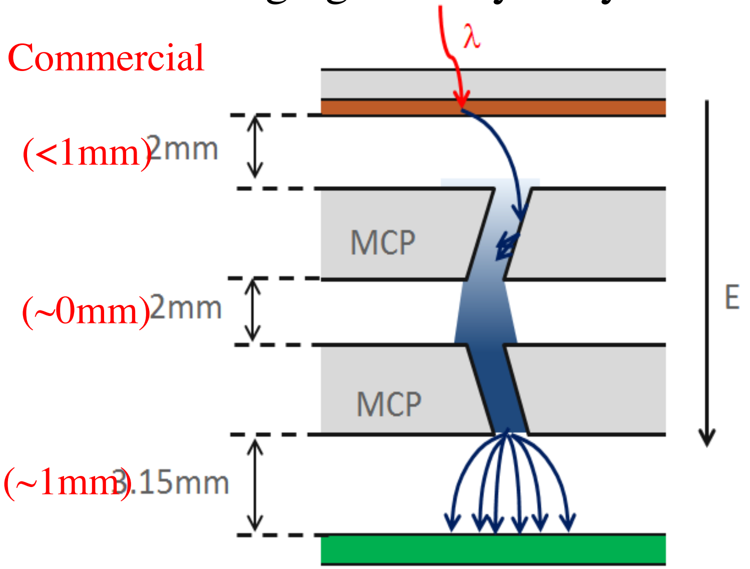
LAPPDs – gain response in high-B fields



Factor of x5-x6 loss by 100 mT (B ~ 0.5 T

Total loss > 250 mT (B~1T)

Design guided by early LAPPD simulations



Summary

- ✧ ***Spacing too large to prevent significant electron drift***
- ✧ ***New version available for JLAB***
- ✧ Will include variable voltage divider setup, so online optimization may be possible
- ✧ Hopefully spacing issue can be addressed in a future version
- ✧ Pad readout can help in minimizing size

Time-of-Flight (TOF)

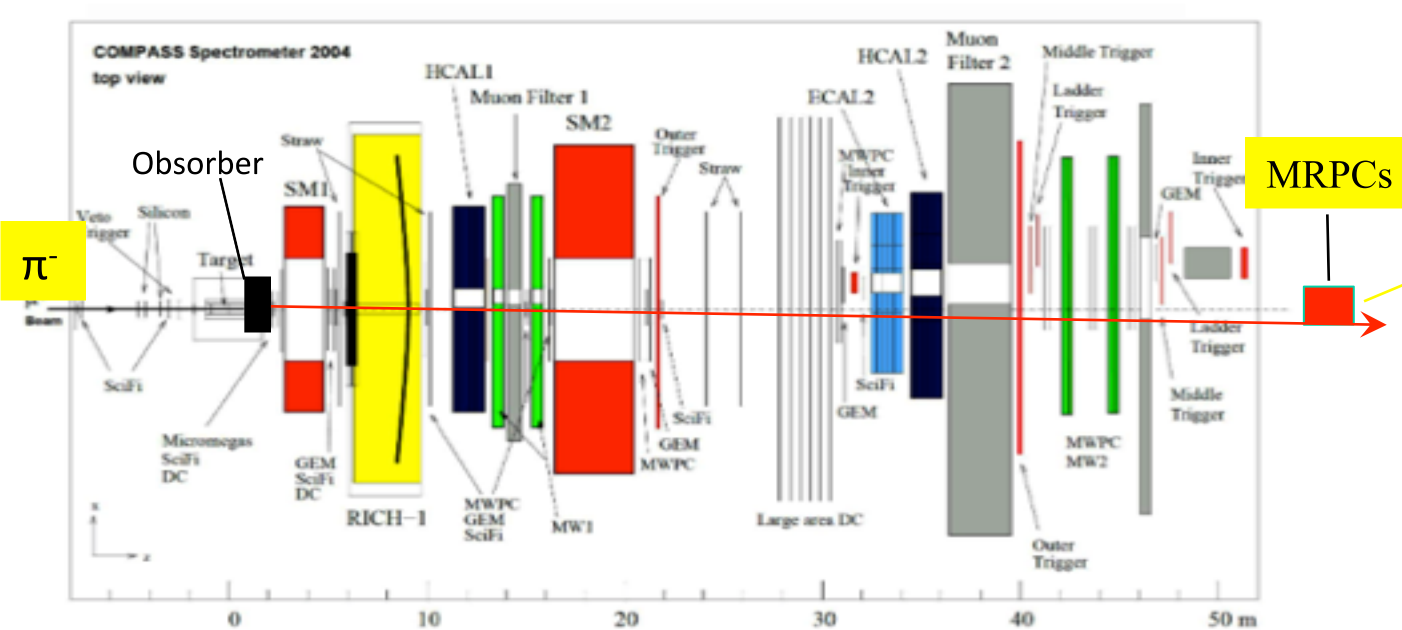
1. Rate Tests of UIUC glass mRPC prototype in test beam (UIUC)
   Tentative conclusion that prototypes can handle ~100 Hz
2. See first signals from 3D printed mRPCs (UIUC)
3. Progress on Garfield++ Simulations (Howard, BNL)
4. Preamp board developed based on TI LMH5401, with gain of 16 and 900 MHz analog bandwidth (BNL)

Outlook

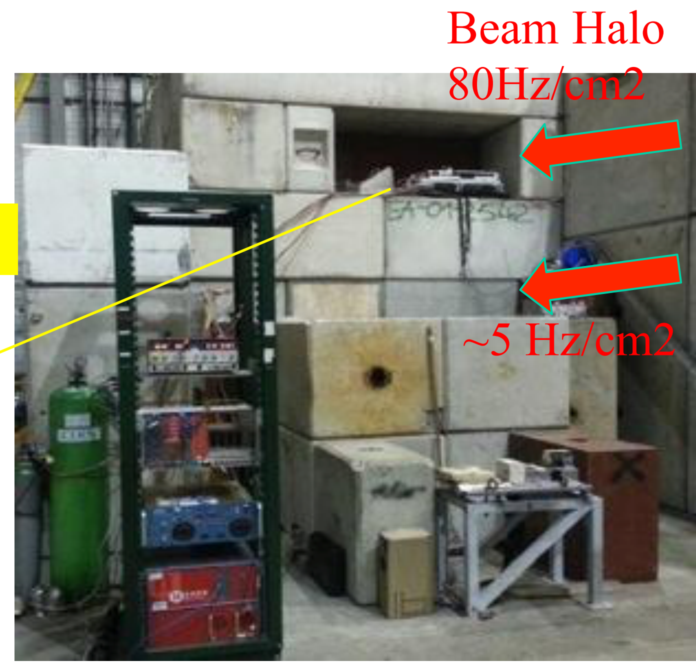
- Beam test in April 2016 at FNAL with RICH group
- Build and test other designs that might allow better signal to noise by increasing number of gas gaps and distance to cathode pickup (eg replace glass with mylar or kapton)
- Continue progress on Garfield++ simulations
- Test and improve preamp
- Detailed studies of where to get start time

TOF – muon beam test at COMPASS, CERN

❖ *MRPC rate capability test, Oct 15th ~ Nov 15th 2015*



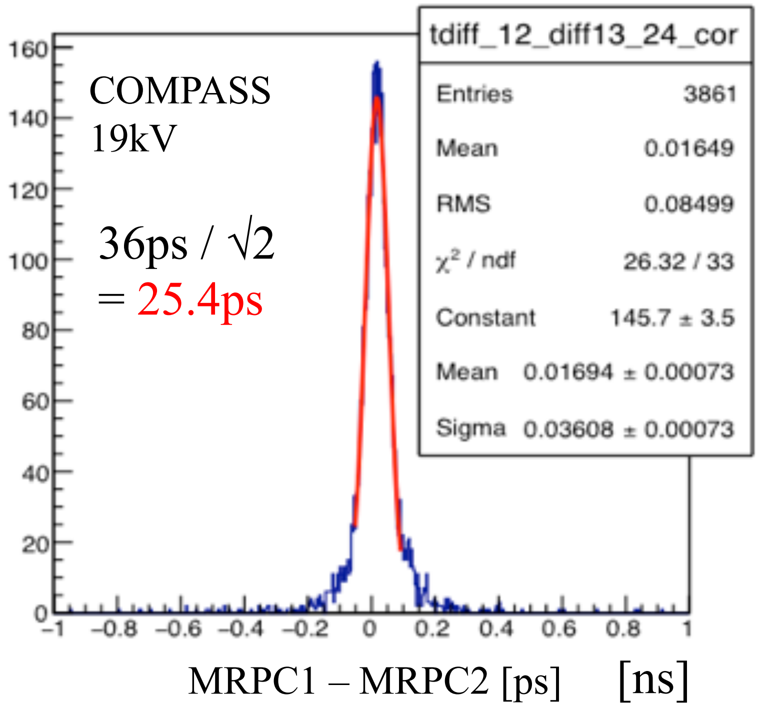
COMPASS Spectrometers

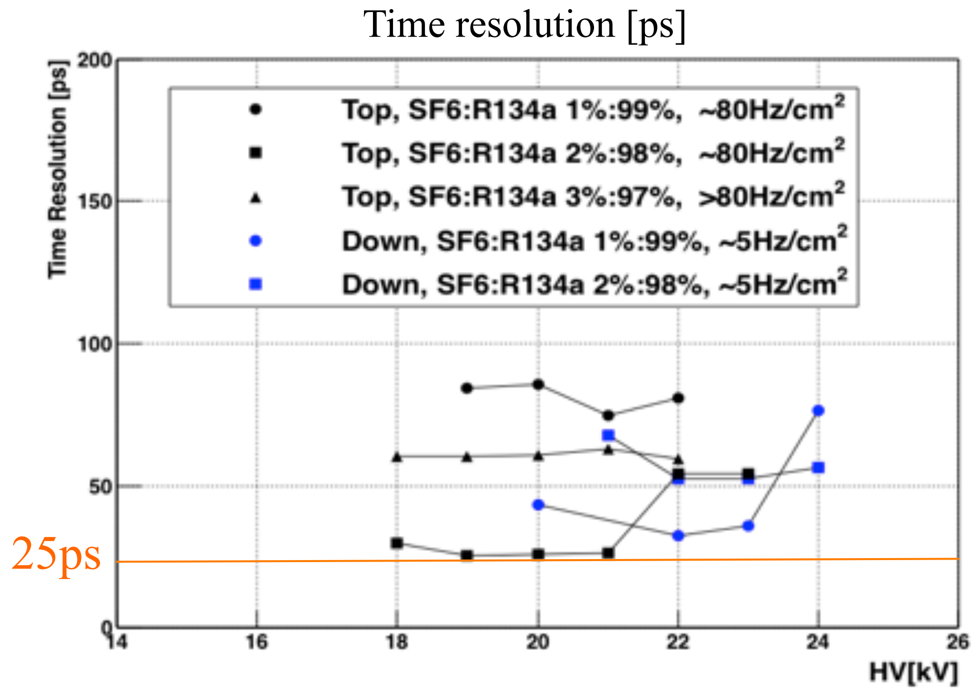


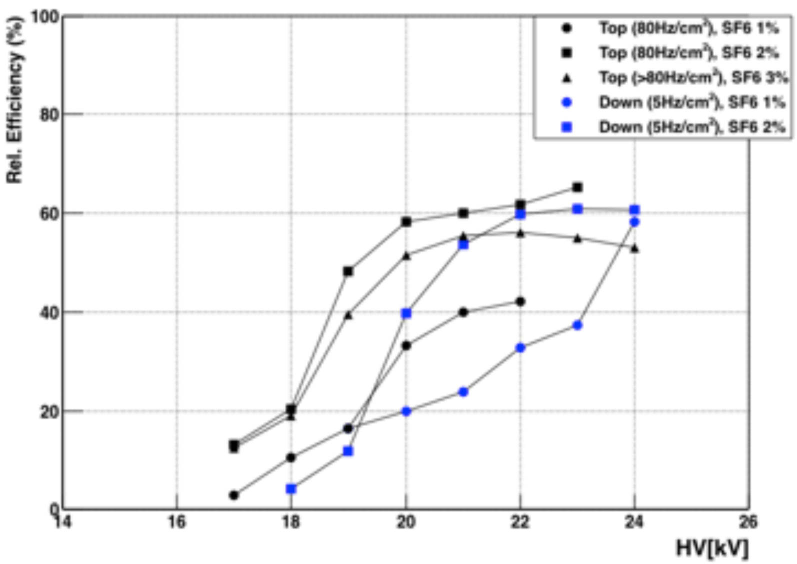
- COMPASS Drell-Yan Run 2015
  - 190 GeV π^- beam, Intensity of 4×10^8 /s
- Setup the MRPCs downstream of the COMPASS detectors
  - Mostly only muons survive
- Varied flux rate by moving the MRPC to up (~80 Hz/cm^2) and down (~5 Hz/cm^2) positions

Two MRPCs in the same gas chamber

TOF – efficiency and time resolution

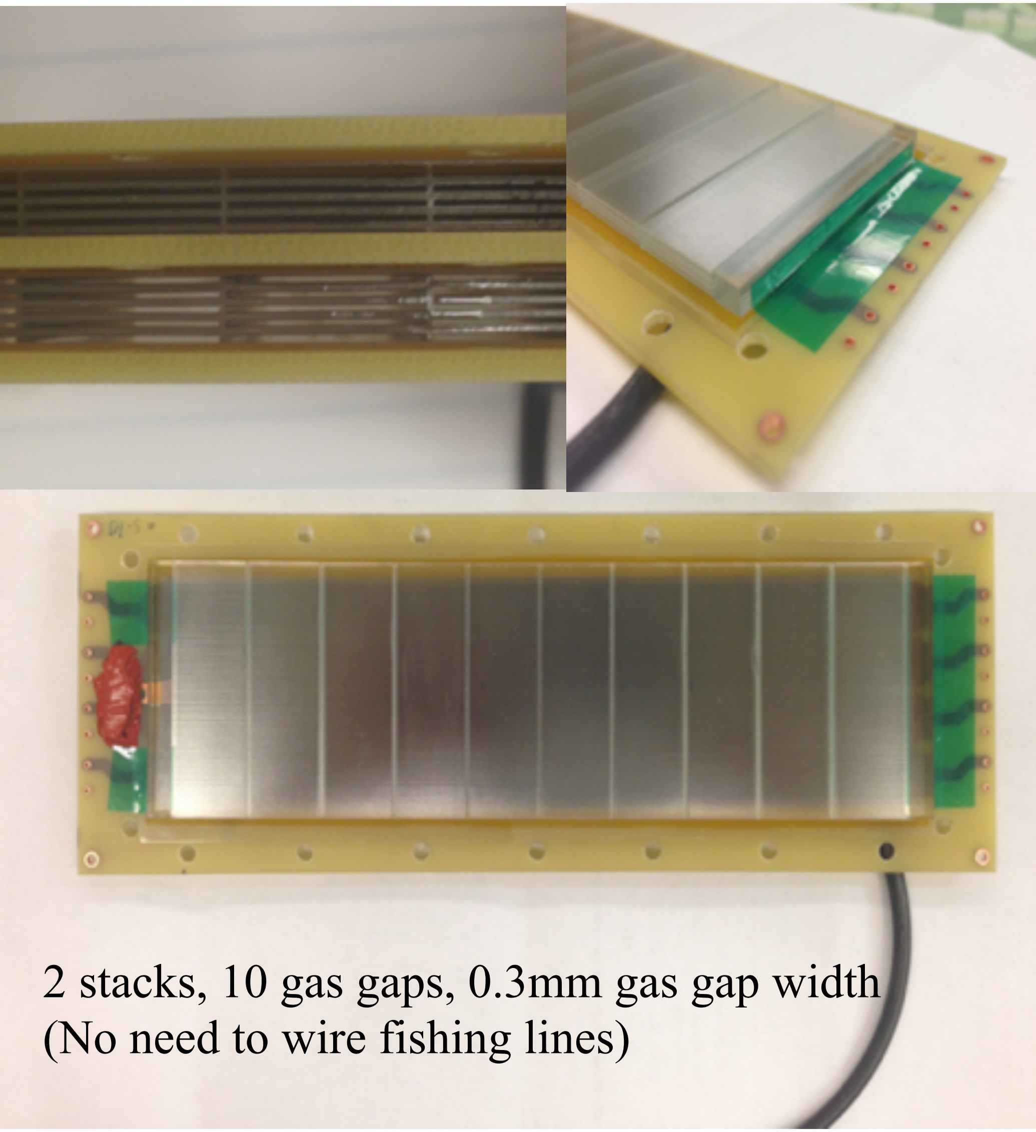


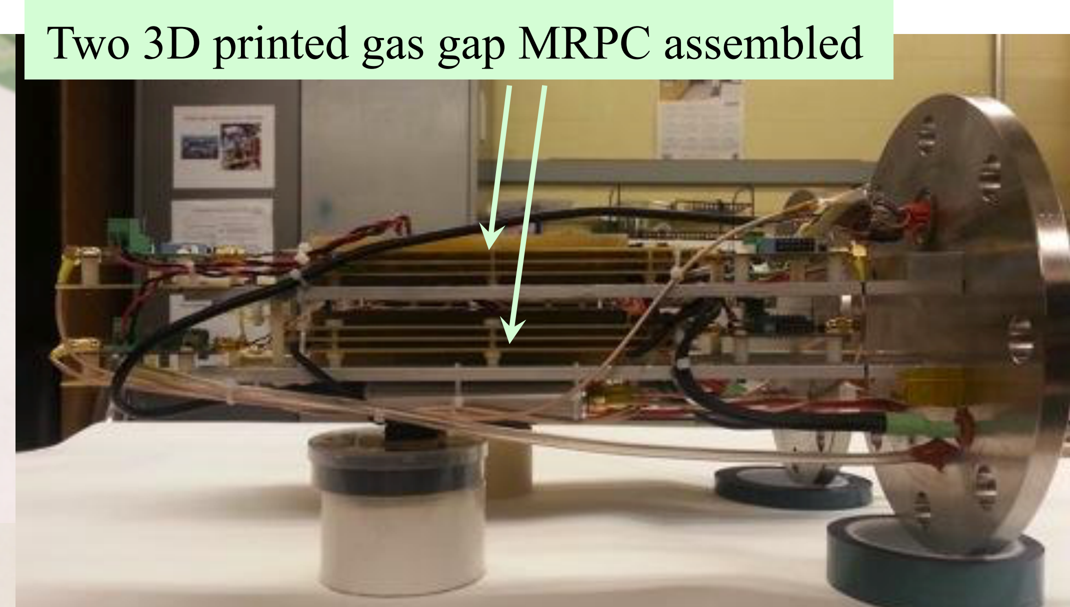


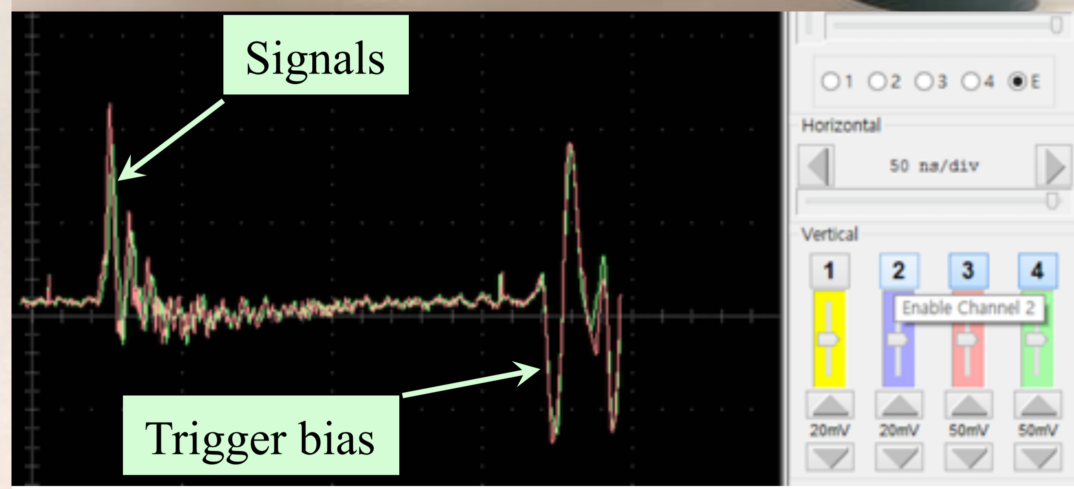


- Obtained 25.4ps with flux rate of 80Hz/cm^2
- Overall efficiency results are lower than cosmic ray
  - Background issue? (no tracking system)
- Efficiency results on 5Hz/cm^2 lower than on the 80Hz/cm^2
  - Possibly due to gas pressure issue
- Will be followed up with beam test at Fermilab in April 2016

TOF – first signals from 3D printed MRPCs





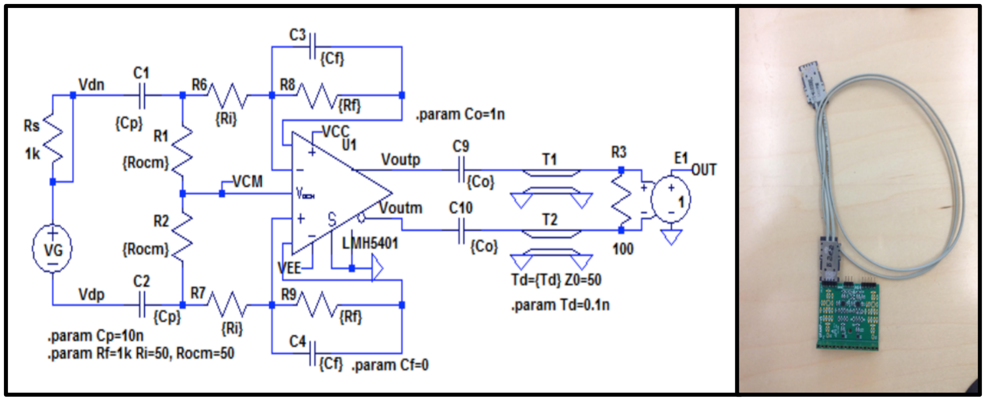


Signals captured at COMPASS hall

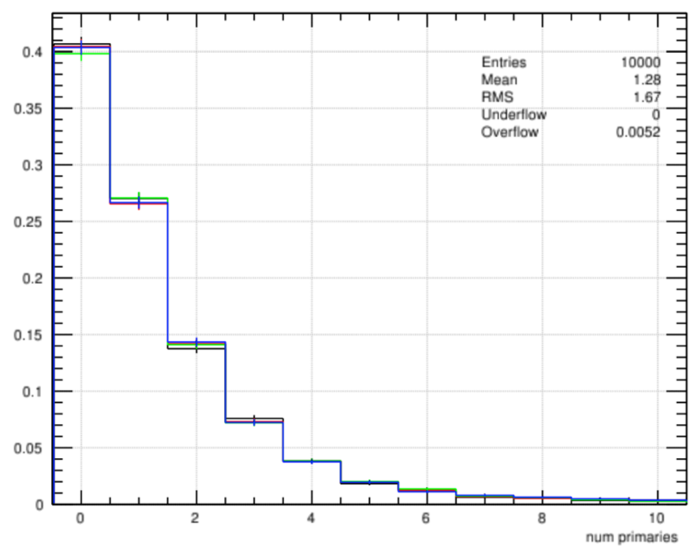
- Not enough time to setup 3D MRPC properly for data taking before the COMPASS beam ended
- Expect the first time resolution results in cosmics and in the test beam at FNAL April 2016

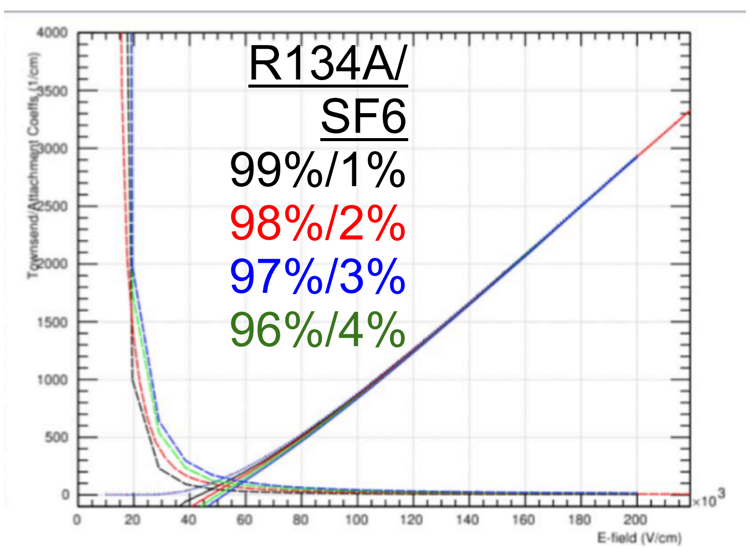
TOF – electronics and simulation development

- Fast preamp under testing (900 MHz and 16 gain)
  - Allows many more channels to be read out
  - Already likely to need a rev. 2 due to stray parasitic capacitance left in circuit



- Garfield++ Simulations started
  - Doing detailed studies with pressure changes to understand beam test results
  - Have basic gas properties now, need to implement avalanche and signal propagation





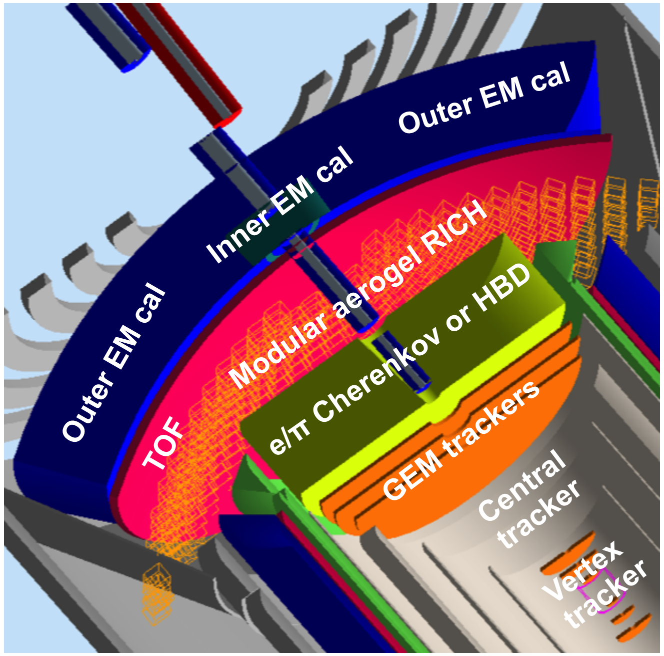
Inter-consortium PID: e/π identification

Electron ID spans multiple consortia: PID, calorimetry, tracking

Compact dual-use systems particularly interesting R&D topics

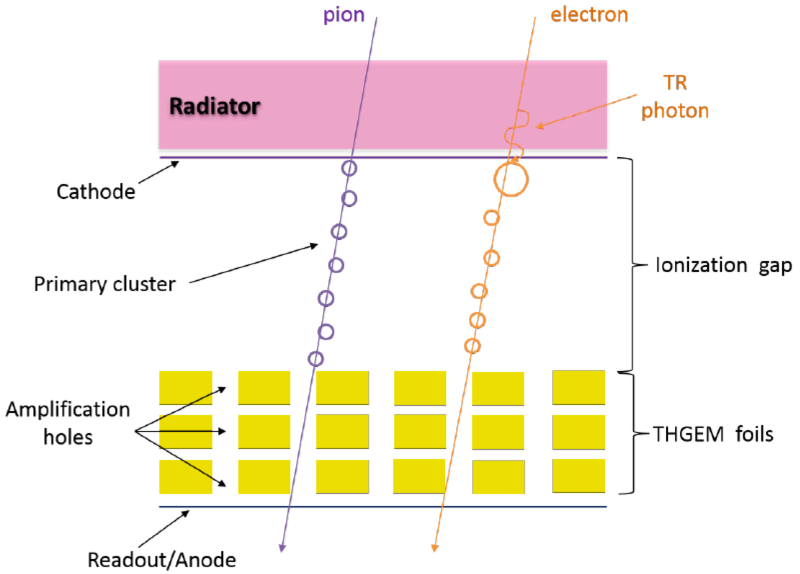
communication and coordination required!

e-endcap: HBD with radial TPC?



- Significant backgrounds from low-momentum pions in the e-endcap
- Hadron Blind Detector (along z-axis) could provide e/π ID up to 4 GeV/c
- Radial TPC can use the same gas volume for cost-effective tracking in the e-endcap

h-endcap: GEM-based TRD?

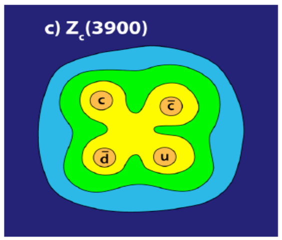


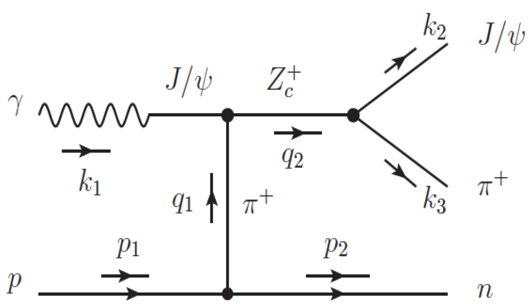
2011 EIC R&D proposal (arXiv:1412:4769)

- Leptonic decays of hadrons (and detection of backscatterd electrons) require e/hadron ID over a wide momentum range in the h-endcap
- A TRD integrated with the GEM tracker could cover 2-100 GeV/c

e/π identification requirements in hadron endcap - example: spectroscopy of XYZ states

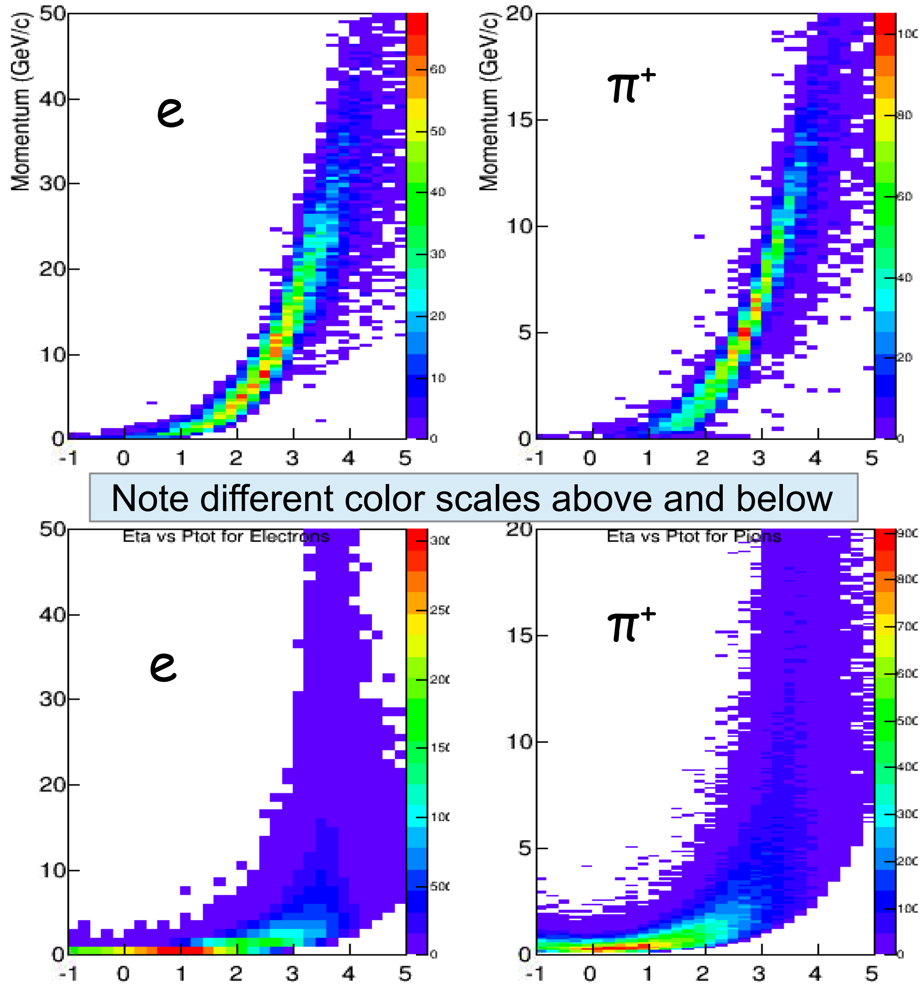
Tetraquark



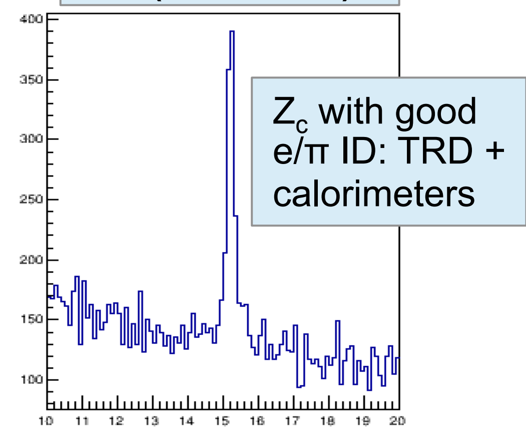


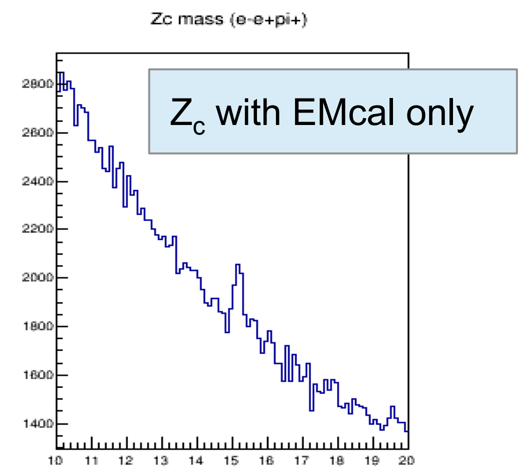
- Cross section:
  $\sigma(Z_c[3900]) \sim 5$ nb
  $\sigma(Q^2 < 1 GeV) \sim 50$ µb

5 on 50 GeV beams, electron in low-Q^2 tagger



$Z_c[3900]$
$m^2(e+e-\pi+)$





- Spectroscopy of heavy quark systems (lineshape, PWA, etc) is one of the topics that would greatly benefit from good high-momentum e/π ID in the hadron endcap

Summary and Outlook

1. Lots of progress!

- First publications submitted, more to come!
- More details in progress report

2. Close collaboration within the eRD14

- Bi-weekly consortium meetings
- In-person meetings at DNP in Santa Fe, UGM in Berkeley, and both the previous and this current EIC R&D meetings
- Lots of discussion across project groups

3. Initial focus on hadron ID, but extension to electron ID natural

- HBD, TRD, etc, are being considered for EIC detectors
- Collaboration with tracking (and calorimetry) consortia important

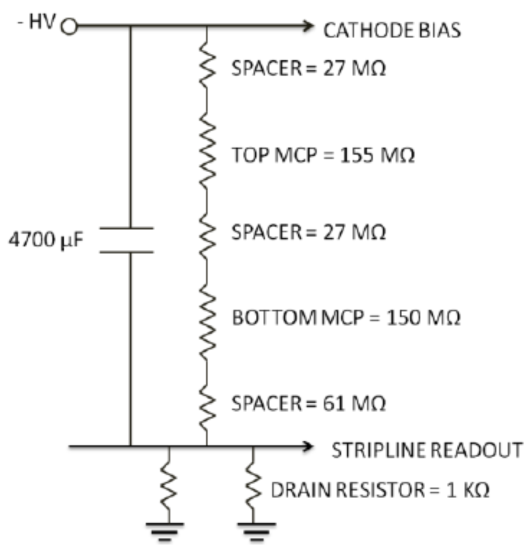
Backup

Table of 6cm Tube Characteristics

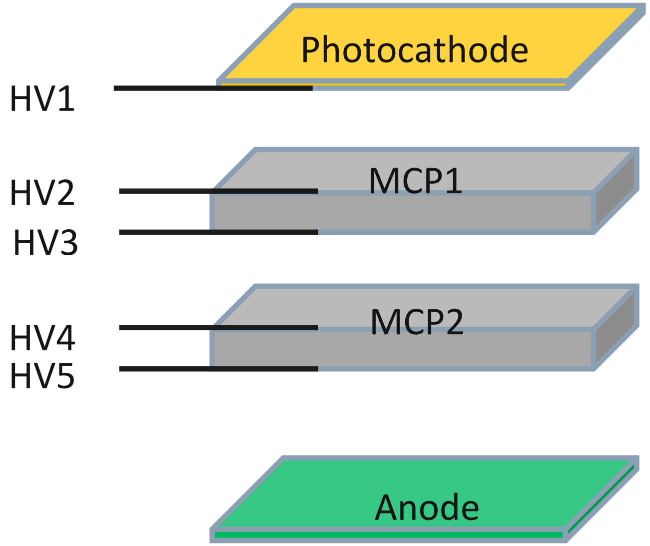
	Completion Date	QE at 350nm (%)	Gain (900V) Single PE	Avg. Response for <NPE> = 10 (pC) ±RMS	SPE Overall Time Resolution at 900V (ps)
Tube 44	Jun 10, 2015	6	1.5×10^{7}	7.5±2.4	33.5
Tube 45	Jun 24, 2015	6	3.4×10^{7}	8.0±1.6	35.6
Tube 46	Aug 5, 2015	11	no op	no op	no op
Tube 47	Aug 26, 2015	14	4.5×10^{6} (950V)	3.2±1.2	95 (950V)
Tube 48	Sep 23, 2015	3.5	7.5×10^{6}	5.6±2.7	101.9
Tube 49	Oct 7, 2015	7.4	5.0×10^{7}	10.9±6.9	34.7
Tube 50	Nov 6, 2015	6.3	5.5×10^{6}	2.2±0.2	54.2
Tube 51	11/20/2015	10.5	5.4×10^{6}	2.9±0.6	35.0
Tube 52	12/3/2015	10.0	1.7×10^{6}	1.8±0.7	48.5
Tube 53	12/17/2015	6.9	1.5×10^{6}	0.5±0.5	65
Tube 54	12/31/2015	13.2	1.3×10^{7}	9.6±3.5	45
Tube 55	1/7/2016	12.8	Photocathode only tube		
Tube 56	1/15/2016	12.9	Photocathode only tube		

IBD-1 Devices: Independently Biased Design

Version-0 : Internal resistance chain design



IBD-1: Independently biased design (IBD)



Limitation of the Internal resistance chain design:

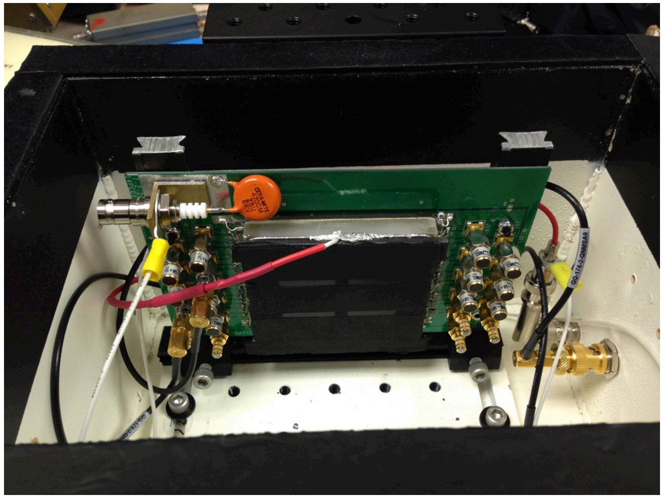
- Need fine matching between component resistances
- No direct QE measurement in sealed tube
- Can't optimize each internal component

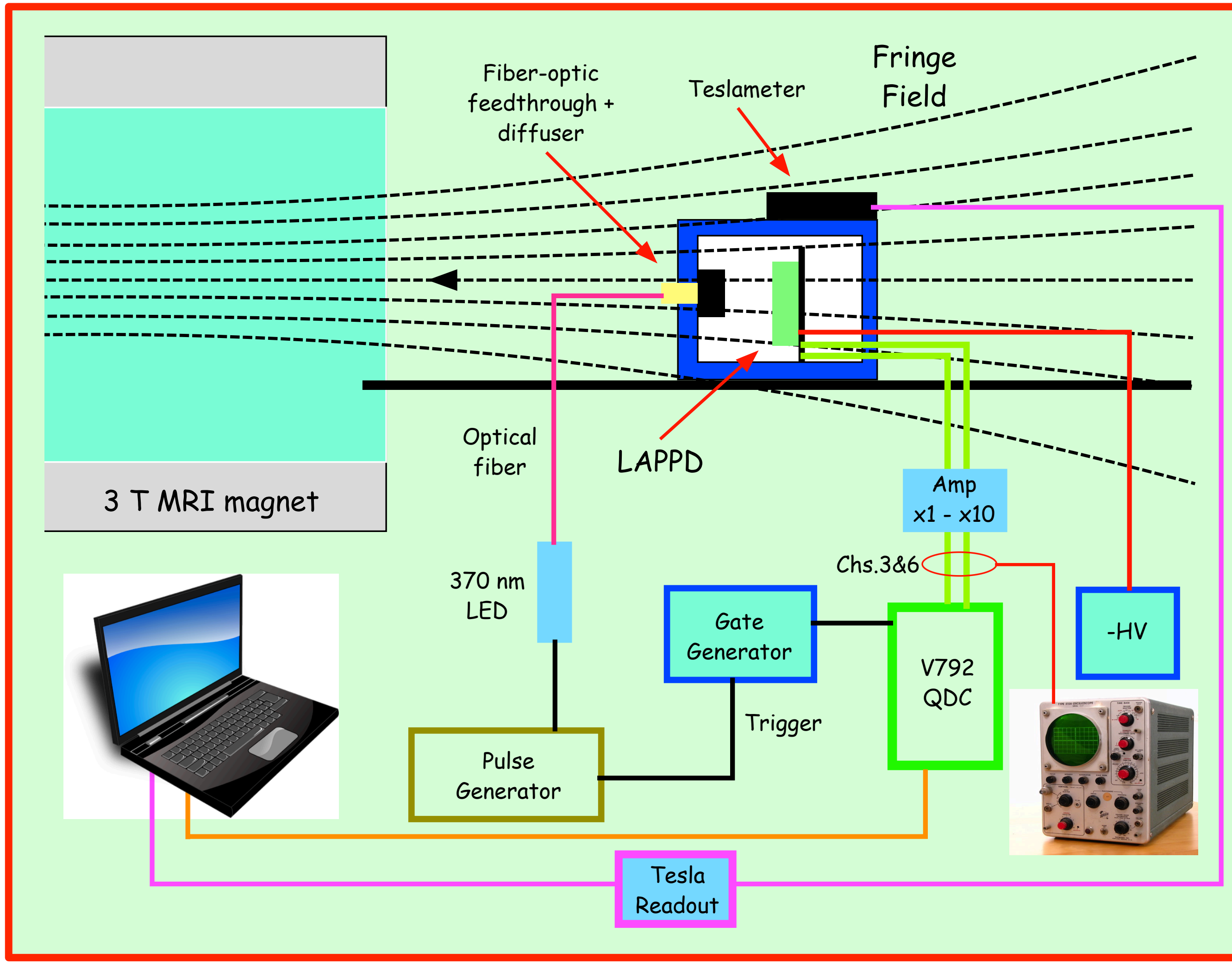
Status of the IBD-1 tubes:

- **5 working tubes; process yield > 90%**
- On track for 10 functional tubes by year end
- Will release first tubes to outside users in near future (few weeks)
- Can now optimize performance of each stage
- Next improvement: adjust gap spacings

LAPPD Magnetic Field Test Setup

- Tests conducted at UVA Biomedical Eng. Dept. – 3T MRI magnet





Contact: Carl Zorn, Jefferson Lab